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**FLIGHT SUPPORT TESTING OF THE J-2 ROCKET  
ENGINE IN PROPULSION ENGINE TEST CELL (J-4)  
(TESTS J4-1901-07 AND J4-1901-08)**

**J. N. Simpson and C. E. Pillow**

**ARO, Inc.**

**January 1969**

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## FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (I-E-J), under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2 rocket engine, and McDonnell Douglas Corporation, Douglas Aircraft Company, Missile and Space Systems Division, manufacturer of the S-IVB stage. The testing reported herein was conducted on August 21 and 27, 1968, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1901. The manuscript was submitted for publication on October 24, 1968.

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This technical report has been reviewed and is approved.

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## ABSTRACT

Ten firings of the Rocketdyne J-2 rocket engine (S/N J-2036-1) were conducted during two test periods (J4-1901-07 and J4-1901-08) on August 21 and 27, 1968, in Test Cell J-4 of the Large Rocket Facility. This testing was in support of the Saturn V vehicle. The firings were accomplished at pressure altitudes between 93,000 and 102,000 ft at engine start. The primary objective of these firings was to evaluate transient gas generator temperatures under simulated engine first burn and restart conditions. Transient gas generator temperatures, particularly on engine restarts, were significantly reduced by utilizing a gas generator oxidizer supply line assembly which incorporated a geometrically different bellows section. The supply line assembly utilized on this series of firings had a 1.7 percent greater pressure drop at a flow of 3.5 lb<sub>m</sub>/sec. The total accumulated firing duration for these tests was 163 sec.

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*For Mr. Letter  
J4-4. 2 July 74  
signed William O.  
Cole.*

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## NOMENCLATURE

|                |  |
|----------------|--|
| A              | Area, in. <sup>2</sup>   |
| ASI            | Augmented spark igniter  |
| ES             | Engine start, designated as the time that helium control<br>and ignition phase solenoids are energized                                       |
| GG             | Gas generator  |
| MOV            | Main oxidizer valve  |
| STDV           | Start tank discharge valve   |
| t <sub>0</sub> | Defined as the time at which the opening signal is applied<br>to the start tank discharge valve solenoid                                     |
| VSC            | Vibration safety counts, defined as the time at which engine<br>vibration was in excess of 150 g rms in a 960- to 6000-Hz<br>frequency range |

## SUBSCRIPTS

|   |        |
|---|--------|
| f | Force  |
| m | Mass   |
| t | Throat |

## SECTION I INTRODUCTION

Testing of the Rocketdyne J-2 rocket engine using an S-IVB battleship stage has been in progress since July, 1966, at AEDC in support of J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The ten firings reported herein were conducted during test periods J4-1901-07 and J4-1901-08 in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF). These firings were to investigate engine start transients for both S-IVB first burn, 80-min orbital restarts, and an S-II start utilizing a 230,000-lbf-thrust configuration engine. The firings were accomplished at pressure altitudes ranging from 93,000 to 102,000 ft (geometric pressure altitude,  $\bar{Z}$ , Ref. 1) at engine start. Engine components were conditioned to temperatures predicted for an S-IVB first burn, 80-min restart, or S-II start. Data collected to accomplish the test objectives are presented herein. The results of the previous test period are presented in Ref. 2.

## SECTION II APPARATUS

### 2.1 TEST ARTICLE

The test article was a J-2 rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 230,000 lbf at an oxidizer-to-fuel mixture ratio of 5.5. The engine, as received at AEDC, was designated S/N J-2036-1 signifying that it is a rebuilt engine. In rebuilding, modifications were performed to configure the engine identically with engine S/N J-2072 and subsequent engines. An S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed since the previous test period are presented in Tables III and IV, respectively.

### 2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5, Ref. 3) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in. -diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic length ( $L^*$ ) of 24.6 in., a 170.4-in.<sup>2</sup> throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.
2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer port orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 in.<sup>2</sup>, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.
3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.
4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 38,215 ft (1248 psia) of liquid hydrogen at a flow rate of 8585 gpm for a rotor speed of 27,265 rpm.
5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 2170 ft (1107 psia) of liquid oxygen at a flow rate of 2965 gpm for a rotor speed of 8688 rpm.
6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel



lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio ( $A/A_t$ ) of approximately 11.

7. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.
8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage prevalves and main propellant valves at engine shutdown.
9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of a 7258-in.<sup>3</sup> sphere for hydrogen with a 1000-in.<sup>3</sup> sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.
10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases which bypass the oxidizer turbine are discharged into the thrust chamber.
11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.
12. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.
13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.
14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.

15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

### 2.1.2 Oxidizer Supply Line to Gas Generator

The gas generator oxidizer supply line assembly (Fig. 3b) utilized on these firings was identical to the assembly utilized on the previous tests (Ref. 2), with the exception of the internal geometry of the flexible bellows section. An X-ray photograph of the bellows section manufactured by the Anaconda American Brass Company is shown in Fig. 3c. An X-ray photograph of the bellows section utilized on the previous tests is shown in Fig. 3d. This bellows section was manufactured by the Avica Corporation. The assemblies P/N 408710 and P/N NA5-260113 are hereafter referred to as the Anaconda and Avica lines, respectively.

### 2.1.3 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46,000 lb of liquid hydrogen and 199,000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant pre-valves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen for fuel tank pressurization during S-IVB and S-II flight was routed to the facility venting system.

## 2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion

systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lbf-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber, crossover duct, start tank discharge valve (firing 08A, only), oxidizer dome (firing 07E, only), and main oxidizer valve second-stage actuator. Helium was routed internally through the crossover duct, oxidizer dome, and tubular-walled thrust

chamber. Helium was routed externally over the start tank discharge valve. Main oxidizer valve conditioning was achieved by opening the pre valves and permitting propellants into the engine.

## 2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-type and capacitance-type (Photocon®, POJ-3) pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the strain-gage-type pressure transducers and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers and the Photocon pressure transducer.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (Microsadic®) scanning each parameter at 40 samples per second and recording on magnetic tape; (2) single-input, continuous-recording FM systems recording on magnetic tape; (3) photographically recording galvanometer oscillographs; (4) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts; and (5) optical data recorders. Applicable systems were calibrated before each test

(atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

## 2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for a normal start and shutdown is presented in Figs. 7a and b. Two control logics for sequencing the stage prevalues and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 7c and d.

## SECTION III PROCEDURE

Preoperational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time,

the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Engine components which required temperature conditioning were the thrust chamber, the crossover duct, start tank discharge valve (firing 08A, only), oxidizer dome (firing 07E, only), and main oxidizer valve second-stage actuator. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing.

## **SECTION IV**

### **RESULTS AND DISCUSSION**

#### **4.1 TEST SUMMARY**

Ten firings of the Rocketdyne J-2 rocket engine (S/N J-2036-1) were conducted during test periods J4-1901-07 and J4-1901-08 on August 21 and 27, 1968, respectively. The principle objective of these tests was to evaluate transient gas generator temperatures at simulated S-IVB engine first burn and restart conditions.

Initial altitude testing of engine S/N J-2036-1 had resulted in high gas generator transient temperatures (Refs. 2 and 5) relative to the temperatures experienced on the previously tested engine (S/N J-2047, Ref. 6, for typical results). Consequently, the engine manufacturer determined that there are internal dimensional differences between the Anaconda and Avica oxidizer supply lines to the gas generator. These tests were conducted to determine the effect on the engine start transient of the line differences.

The engine was operated 163 sec during tests 07 and 08. This resulted in a total accumulated operating time at AEDC on engine S/N J-2036-1 of 583 sec.

#### **4.2 TEST OBJECTIVES AND RESULTS**

Engine configuration changes, Tables III and IV, were performed before each of the tests of this series to obtain the desired objectives. The principle change was the gas generator oxidizer supply line assembly which was replaced before test 07.

In general, these firings investigated the effect of internal geometric differences (Section 2.1.2) of the gas generator oxidizer supply line assembly on transient gas generator temperature. The Anaconda line was utilized on tests 07 and 08; the Avica line was utilized in Ref. 2.

Test requirements and specific conditions at engine start for all firings are presented in Table VI. Start and shutdown operating times of principle engine valves are presented in Table VII. Calculated engine steady-stage performance data are shown in Table VIII. Primary engine starting requirements are shown in Fig. 8.

The following sections will consist of discussions and analysis of selected firings. The data presented will be those recorded on the digital data acquisition system, except as noted.

#### 4.2.1 Firing J4-1901-07A

##### 4.2.1.1 Objectives

Objectives were to perform an S-IVB engine first burn to evaluate augmented spark igniter operation and gas generator transient temperature utilizing high start tank energy, minimum fuel pump inlet pressure, and coldest expected thrust chamber preconditioning.

##### 4.2.1.2 Results

The firing of 32.6-sec duration following a 3.0-sec fuel lead was conducted, which satisfied test requirements except for start tank pressure (17 psi below minimum requested value). Temperature histories of thermally conditioned engine components are shown in Fig. 9. Engine start and shutdown transients are shown in Fig. 10. Fuel pump start transient performance is shown in Fig. 11. Engine ambient and combustion chamber pressure histories are shown in Fig. 12. Pressure altitude at engine start was 93,000 ft.

Ignition was detected in the augmented spark igniter 172 msec after engine start. Maximum gas generator transient temperature was 1480°F (first peak). Oxidizer dome prime (chamber pressure = 100 psia) occurred at  $t_0 + 0.982$  sec, initial movement of the second stage of the main oxidizer valve occurred at  $t_0 + 0.982$  sec, and a chamber pressure of 550 psia was attained at  $t_0 + 1.958$  sec. The scheduled propellant utilization valve excursion (null to close) was completed at  $t_0 + 12.0$  sec. Approximately 50 msec of excessive engine vibration (VSC) occurred, beginning at  $t_0 + 0.972$  sec.

Abnormal combustion chamber and propellant systems pressure transients resulted during the oxidizer dome priming sequence (Fig. 10). These pressure transients caused an indicated fuel pump stall condition (Fig. 11), but main-stage operation was successfully attained.

#### 4.2.2 Firing J4-1901-07B

##### 4.2.2.1 Objective

The objective was to perform an S-IVB engine restart after a simulated 80-min orbital coast to evaluate gas generator transient temperature with maximum start tank energy.

##### 4.2.2.2 Results

The firing of 7.6-sec duration following a 7.9-sec fuel lead was conducted 29 min after firing 07A and satisfied test requirements. Temperature histories of thermally conditioned engine components are shown in Fig. 13. Engine start and shutdown transients are shown in Fig. 14. Fuel pump start transient performance is shown in Fig. 15. Engine ambient and combustion chamber pressure histories are shown in Fig. 16. Pressure altitude at engine start was 99,000 ft.

Maximum transient gas generator temperatures were 1210°F (first peak) and 1510°F (second peak). Oxidizer dome prime occurred at  $t_0 + 0.944$  sec, initial movement of the second stage of the main oxidizer valve occurred at  $t_0 + 1.112$  sec, and a chamber pressure of 550 psia was attained at  $t_0 + 2.050$  sec. The propellant utilization valve remained full open as scheduled throughout this firing.

#### 4.2.3 Firing J4-1901-07C

##### 4.2.3.1 Objective

The objective was to perform an S-IVB engine first burn to evaluate augmented spark igniter operation and gas generator transient temperature utilizing low start tank energy, minimum fuel pump inlet pressure, and coldest expected thrust chamber preconditioning.

##### 4.2.3.2 Results

The firing of 32.6-sec duration following a 3.0-sec fuel lead was conducted, which satisfied test requirements. Temperature histories of thermally conditioned engine components are shown in Fig. 17. Engine start and shutdown transients are shown in Fig. 18. Fuel pump



start transient performance is shown in Fig. 19. Engine ambient and combustion chamber pressure histories are shown in Fig. 20. Pressure altitude at engine start was 98,000 ft.

Ignition was detected in the augmented spark igniter 172 msec after engine start. Maximum gas generator transient temperature was 1460°F (first peak). Oxidizer dome prime occurred at  $t_0 + 0.996$  sec, initial movement of the second stage of the main oxidizer valve occurred at  $t_0 + 0.993$  sec, and a chamber pressure of 550 psia was attained at  $t_0 + 1.947$  sec. The scheduled propellant utilization valve excursion (null to close) was completed at  $t_0 + 11.4$  sec. Approximately 35 msec of excessive engine vibration (VSC) occurred at oxidizer dome prime.

#### 4.2.4 Firing J4-1901-07D

##### 4.2.4.1 Objective

The objective was to perform an S-IVB engine restart after a simulated 80-min orbital coast to evaluate gas generator transient temperature with maximum start tank energy.

##### 4.2.4.2 Results

The firing of 7.6-sec duration following a 7.9-sec fuel lead was conducted 27 min after firing 07C and satisfied test requirements. Temperature histories of thermally conditioned engine components are shown in Fig. 21. Engine start and shutdown transients are shown in Fig. 22. Fuel pump start transient performance is shown in Fig. 23. Engine ambient and combustion chamber pressure histories are shown in Fig. 24. Pressure altitude at engine start was 99,000 ft.

Maximum transient gas generator temperatures were 1400°F (first peak) and 1510°F (second peak). Oxidizer dome prime occurred at  $t_0 + 0.958$  sec, initial movement of the second stage of the main oxidizer valve occurred at  $t_0 + 1.088$  sec, and a chamber pressure of 550 psia was attained at  $t_0 + 2.050$  sec. The propellant utilization valve remained full open as scheduled throughout this firing.

#### 4.2.5 Firing J4-1901-07E

##### 4.2.5.1 Objective

The objective was to perform a partial transition test to evaluate the effect of a prechilled oxidizer dome on the engine start transient.

#### 4.2.5.2 Results

The firing of 1.3-sec duration following a 3.0-sec fuel lead was conducted, which satisfied test requirements except for oxidizer pump inlet temperature (1.5°F above maximum requested value). Temperature histories of thermally conditioned engine components are shown in Fig. 25. Engine start and shutdown transients are shown in Fig. 26. Fuel pump start transient performance is shown in Fig. 27. Engine ambient and combustion chamber pressure histories are shown in Fig. 28. Pressure altitude at engine start was 101,000 ft.

Ignition was detected in the augmented spark igniter 240 msec after engine start. Maximum gas generator transient temperature was 800°F (first peak). Oxidizer dome prime (initial) occurred at  $t_0 + 0.967$  sec, and initial movement of the second stage of the main oxidizer valve occurred at  $t_0 + 0.986$  sec. The propellant utilization valve remained in the null position as scheduled throughout this firing. Approximately 43 msec of excessive engine vibration (VSC) occurred, beginning at  $t_0 + 0.952$  sec; a second period of 158 msec of excessive engine vibration occurred, beginning at  $t_0 + 1.117$  sec and continuing until shortly after engine cutoff signal ( $t_0 + 1.250$  sec).

Abnormal combustion chamber and propellant systems pressure transients resulted during the oxidizer dome priming sequence (Fig. 26). These pressure transients were similar to those experienced on firing 07A, except the initial chamber pressure peak was not as great as on firing 07A. The initial chamber pressure peak on firing 07E resulted in a minimum fuel pump stall margin (Fig. 27) of 1100 gpm at approximately 13,000 rpm, whereas an indicated stall condition occurred during firing 07A.

#### 4.2.6 Firing J4-1901-08A

##### 4.2.6.1 Objective

The objective was to perform an engine start at simulated S-II engine conditions to evaluate the operation of the augmented spark igniter with maximum fuel pump inlet pressure and warmest expected thrust chamber preconditioning.

##### 4.2.6.2 Results

The firing of 32.6-sec duration following a 1.0-sec fuel lead was conducted satisfying test requirements, except for start tank pressure

(15 psi below minimum requested value) and oxidizer pump inlet pressure (0.8 psi above maximum requested value). Temperature histories of thermally conditioned engine components are shown in Fig. 29. Engine start and shutdown transients are shown in Fig. 30. Fuel pump start transient performance is shown in Fig. 31. Engine ambient and combustion chamber pressure histories are shown in Fig. 32. Pressure altitude at engine start was 90,000 ft.

Ignition was detected in the augmented spark igniter 504 msec after engine start. Maximum gas generator transient temperature was 930°F (first peak). Oxidizer dome prime occurred at  $t_0 + 0.997$  sec, initial movement of the second stage of the main oxidizer valve occurred at  $t_0 + 0.975$  sec, and a chamber pressure of 550 psia was attained at  $t_0 + 1.975$  sec. The scheduled propellant utilization valve excursion (null to close) was completed at  $t_0 + 13.3$  sec.

This firing was conducted at essentially the same test conditions as was S-II firing 02D (Ref. 5), during which ignition was not detected in the augmented spark igniter. However, the depth of the ignition detect probe into the combustion chamber of the augmented spark igniter had been increased about 0.024 in. between these firings. Ignition detection on firing 08A indicates that combustion probably occurred in the augmented spark igniter on firing 02D but was not satisfactorily detected.

#### 4.2.7 Firing J4-1901-08B

##### 4.2.7.1 Objective

The objective was to perform an S-IVB engine restart after a simulated 80-min orbital coast to evaluate gas generator transient temperatures. This firing repeated firing 07B.

##### 4.2.7.2 Results

The firing of 7.6-sec duration following a 7.9-sec fuel lead was conducted 28 min after firing 08A and satisfied test requirements. Temperature histories of thermally conditioned engine components are shown in Fig. 33. Engine start and shutdown transients are shown in Fig. 34. Fuel pump start transient performance is shown in Fig. 35. Engine ambient and combustion chamber pressure histories are shown in Fig. 36. Pressure altitude at engine start was 102,000 ft.

Maximum transient gas generator temperatures were 1210°F (first peak) and 1460°F (second peak). Oxidizer dome prime occurred at  $t_0 + 0.949$  sec, initial movement of the second stage of the main oxidizer valve occurred at  $t_0 + 1.093$  sec, and a chamber pressure of 550 psia was attained at  $t_0 + 2.060$  sec. The propellant utilization valve remained full open as scheduled throughout this firing.

Firing 08B, conducted at the same starting conditions as firing 07B, yielded essentially identical start transient results. Maximum transient gas generator temperatures (first peak) agreed; second peak temperatures differed by only 50°F. The time required for chamber pressure to attain 550 psia differed by less than 10 msec.

#### 4.2.8 Firing J4-1901-08C

##### 4.2.8.1 Objective

The objective was to perform an S-IVB engine first burn to evaluate engine start transient at maximum start tank energy and warmest expected thrust chamber preconditioning.

##### 4.2.8.2 Results

The firing of 32.6-sec duration, following a 3.0-sec fuel lead, was conducted which satisfied test requirements except for start tank pressure (23 psi below minimum requested value). Temperature histories of thermally conditioned engine components are shown in Fig. 37. Engine start and shutdown transients are shown in Fig. 38. Fuel pump start transient performance is shown in Fig. 39. Engine ambient and combustion chamber pressure histories are shown in Fig. 40. Pressure altitude at engine start was 100,000 ft.

Maximum gas generator transient temperatures were 1380°F (first peak) and 1420°F (second peak). Oxidizer dome prime occurred at  $t_0 + 0.962$  sec, initial movement of the second stage of the main oxidizer valve occurred at  $t_0 + 0.989$  sec, and a chamber pressure of 550 psia was attained at  $t_0 + 1.850$  sec. The scheduled propellant utilization valve excursion (null to close) was completed at  $t_0 + 6.6$  sec (inadvertently premature by 3.4 sec). Approximately 24 msec of excessive engine vibration occurred at oxidizer dome prime.

#### 4.2.9 Firing J4-1901-08D

##### 4.2.9.1 Objective

The objective was to perform an S-IVB engine restart after a simulated 80-min orbital coast to evaluate augmented spark igniter

operation and gas generator transient temperature with maximum start tank energy.

#### 4.2.9.2 Results

The firing of 7.6-sec duration, following a 7.9-sec fuel lead, was conducted 31 min after firing 08C and satisfied test requirements. Temperature histories of thermally conditioned engine components are shown in Fig. 41. Engine start and shutdown transients are shown in Fig. 42. Fuel pump start transient performance is shown in Fig. 43. Engine ambient and combustion chamber pressure histories are shown in Fig. 44. Pressure altitude at engine start was 100,000 ft.

Ignition was detected in the augmented spark igniter 240 msec after engine start. Maximum gas generator transient temperatures were 1200°F (first peak) and 1460°F (second peak). Oxidizer dome prime occurred at  $t_0 + 0.962$  sec, initial movement of the second stage of the main oxidizer valve occurred at  $t_0 + 1.097$  sec, and a chamber pressure of 550 psia was attained at  $t_0 + 2.033$  sec. The propellant utilization valve remained full open as scheduled throughout this firing.

#### 4.2.10 Firing J4-1901-08E

##### 4.2.10.1 Objective

The objective was to perform a partial transition test to evaluate augmented spark igniter operation and gas generator transient temperature utilizing minimum fuel pump inlet pressure and coldest expected thrust chamber preconditioning.

##### 4.2.10.2 Results

The firing of 1.3-sec duration following a 3.0-sec fuel lead was conducted, which satisfied test requirements. Temperature histories of thermally conditioned engine components are shown in Fig. 45. Engine start and shutdown transients are shown in Fig. 46. Fuel pump start transient performance is shown in Fig. 47. Engine ambient and combustion chamber pressure histories are shown in Fig. 48. Pressure altitude at engine start was 102,000 ft.

Ignition was detected in the augmented spark igniter 165 msec after engine start. Maximum gas generator transient temperature was 1520°F (first peak). Oxidizer dome prime occurred at  $t_0 + 0.803$  sec, and initial movement of the second stage of the main oxidizer valve occurred at  $t_0 + 1.037$  sec. The propellant utilization valve remained in the null position as scheduled throughout this firing.

Abnormal combustion chamber and propellant systems pressure transients resulted during the oxidizer dome priming sequence (Fig. 46). These pressure transients were much earlier (about 170 msec) than those experienced on firing 07A, although the initial chamber pressure peak was not as great as on firing 07A. The minimum fuel pump stall margin (Fig. 47) was 1200 gpm at approximately 13,600 rpm on firing 08E.

### 4.3 GAS GENERATOR OXIDIZER SUPPLY LINE EFFECT

The effect of internal geometric differences of the gas generator oxidizer supply line assembly on the transient gas generator temperature and steady-state performance is discussed in the following sections. The Anaconda line was utilized on tests 07 and 08 (P/N 408710, S/N 3729063); the Avica line was utilized on tests 03 and 04 (P/N NA5-260113, S/N 045, Ref. 2).

#### 4.3.1 Transient Performance

Specific test conditions at engine start for the S-IVB 80-min orbital coast restart simulations conducted during tests 03 and 04 (three firings) compared closely with S-IVB 80-min orbital coast restart simulations conducted during tests 07 and 08 (three firings). Tabulated below are the ranges of test conditions attained.

| <u>Tests</u>  | <u>J4-1901-03 and<br/>04</u> | <u>J4-1901-07 and<br/>08</u> |
|---|------------------------------|------------------------------|
| Gas Generator<br>Oxidizer Supply Line<br>Assembly (P/N) | Avica<br>NA5-260113          | Anaconda<br>408710           |
| Fuel Pump Inlet<br>Pressure, psia                       | 27.0 to 40.8                 | 26.7 to 41.0                 |
| Fuel Pump Inlet<br>Temperature, °F                      | -421.1 to -421.3             | -421.0 to -421.3             |
| Oxidizer Pump Inlet<br>Pressure, psia                   | 45.0 to 45.8                 | 45.0 to 45.5                 |
| Oxidizer Pump Inlet<br>Temperature, °F                  | -294.8 to -295.2             | -294.7 to -295.2             |
| Start Tank Pressure,<br>psia                            | 1291 to 1297                 | 1298 to 1303                 |

| <u>Tests</u>  | <u>J4-1901-03 and<br/>04</u> | <u>J4-1901-07 and<br/>08</u> |
|---|------------------------------|------------------------------|
| Start Tank Temperature, °F                              | -262 to -268                 | -265 to -269                 |
| Average Thrust Chamber Temperature, °F, at Engine Start | 33 to 45                     | 22 to 29                     |
| Average Thrust Chamber Temperature, °F, at $t_0$        | -262 to -349                 | -277 to -339                 |
| Average Turbine System Temperature, °F                  | 296 to 306                   | 293 to 305                   |

The transient gas generator temperatures of tests J4-1901-07 and 08 were combined to form an envelope and are compared with a similar envelope for tests J4-1901-03 and 04 in Fig. 49. The envelope with the lower level of magnitude corresponded with the Anaconda line. This indicated that the Anaconda line reduced the maximum gas generator initial temperature peak about 790°F and the maximum second temperature peak about 680°F.

#### 4.3.2 Steady-State Performance

Gas generator oxidizer line resistance (from the engine bleed valve to gas generator chamber pressure) was calculated for these two sets of firings, normalized to a standard oxidizer flow rate of 3.5 lb<sub>m</sub>/sec. These data indicate the Anaconda line resistance (252.1 psid) was 1.7 percent greater than the Avica line resistance.

Steady-state performance data for firings 07A, 07C, 08A, and 08C were calculated (as shown in Appendix IV) and are presented in Table VIII. Selected calculated parameters from the normalized performance were averaged and are compared below to average normalized performance reduced from firings 03A, 03C, 04C, 06A, and 06C (Ref. 2).

| <u>Tests</u>  | <u>J4-1901-03<br/>through 06</u> | <u>J4-1901-07<br/>and 08</u>        |
|---|----------------------------------|-------------------------------------|
| Gas Generator Oxidizer Line Thrust, lb <sub>f</sub>   | Avica<br>227, 300                | Anaconda<br>225, 500 (-0.8 percent) |
| Total Engine Weight Flow, lb <sub>m</sub> /sec        | 537.4                            | 534.8 (-0.5 percent)                |
| Total Gas Generator Weight Flow, lb <sub>m</sub> /sec | 6.99                             | 6.92 (-1.0 percent)                 |

Apparently the engine steady-state operating point was slightly shifted by the change in the gas generator oxidizer supply line assembly which occurred between these sets of firings (as indicated, engine thrust decreased 0.8 percent). The slight performance shift is attributed to the increase in resistance of the gas generator oxidizer supply line.

#### 4.4 POST-TEST INSPECTION

Inspection after the completion of tests J4-1901-07 and 08 revealed no apparent engine component damage.

### SECTION V SUMMARY OF RESULTS

The results of testing the J-2 rocket engine (S/N J-2036-1) in Propulsion Engine Test Cell J-4 during test periods J4-1901-07 and 08 conducted on August 21 and 27, 1968, respectively, are summarized as follows:

1. The gas generator oxidizer supply line assembly (Anaconda) utilized for this series of S-IVB 80-min orbital coast restart simulations reduced the maximum gas generator initial temperature peak about 790°F and the maximum second peak about 680°F, when compared with the tests utilizing the Avica line (Ref. 2). The Anaconda line resistance (252.1 psid) was 1.7 percent greater than the Avica line resistance at a flow rate of 3.5 lb<sub>m</sub>/sec.
2. Ignition was detected in the augmented spark igniter 504 msec after engine start for an S-II simulation (firing 08A) with maximum fuel pump inlet pressure and warmest expected thrust chamber preconditioning. Ignition was not detected during a previous test (J4-1901-02, Ref. 5) conducted at essentially the same starting conditions as firing 08A. However, the ignition detect probe was 0.024 in. deeper into the combustion chamber of the augmented spark igniter for firing 08A.
3. Abnormal combustion chamber and propellant systems pressure transients resulted during the oxidizer dome priming sequence of firings 07A, 07E, and 08E. These pressure transients caused an indicated fuel pump stall condition during firing 07A, but main-stage operation was successfully attained.



4. The firing with a prechilled oxidizer dome (firing 07E) was characterized by excessive engine vibration (VSC) for 43 msec beginning at  $t_0 + 0.952$  and a second period of 158 msec beginning at  $t_0 + 1.117$  sec, continuing until shortly after engine cutoff signal ( $t_0 + 1.250$  sec).

#### REFERENCES

1. Dublin, M., Sissenwine, N., and Wexler, H. U. S. Standard Atmosphere, 1962. December 1962.
2. Vetter, N. R. "Flight Support Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1901-03 through J4-1901-06)." AEDC-TR-68-238, December 1968.
3. "J-2 Rocket Engine, Technical Manual Engine Data." R-3825-1. August 1965.
4. Test Facilities Handbook (7th Edition). "Large Rocket Facility, Vol. 3." Arnold Engineering Development Center, July 1968.
5. Counts, H. J., Jr., and Kunz, C. H. "Altitude Developmental and Flight Support Testing of the J-2 Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1801-42 through J4-1901-02)." AEDC-TR-68-223, November 1968.
6. Franklin, D. E. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1801-34, J4-1801-35, and J4-1801-36)." AEDC-TR-68-176, October 1968.

**APPENDIXES**

- I. ILLUSTRATIONS**
- II. TABLES**
- III. INSTRUMENTATION**
- IV. METHOD OF CALCULATION (PERFORMANCE PROGRAM)**

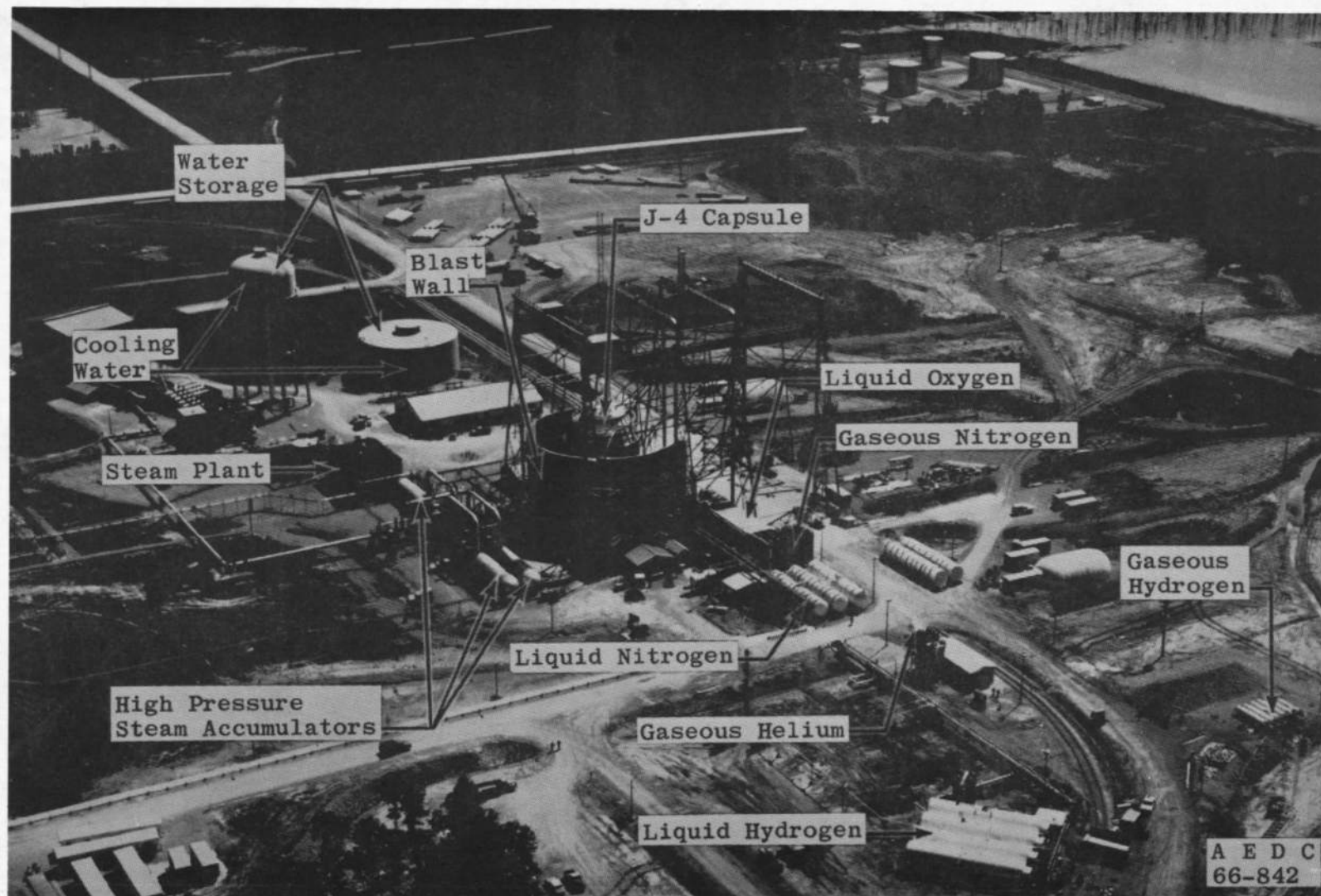


Fig. 1 Test Cell J-4 Complex

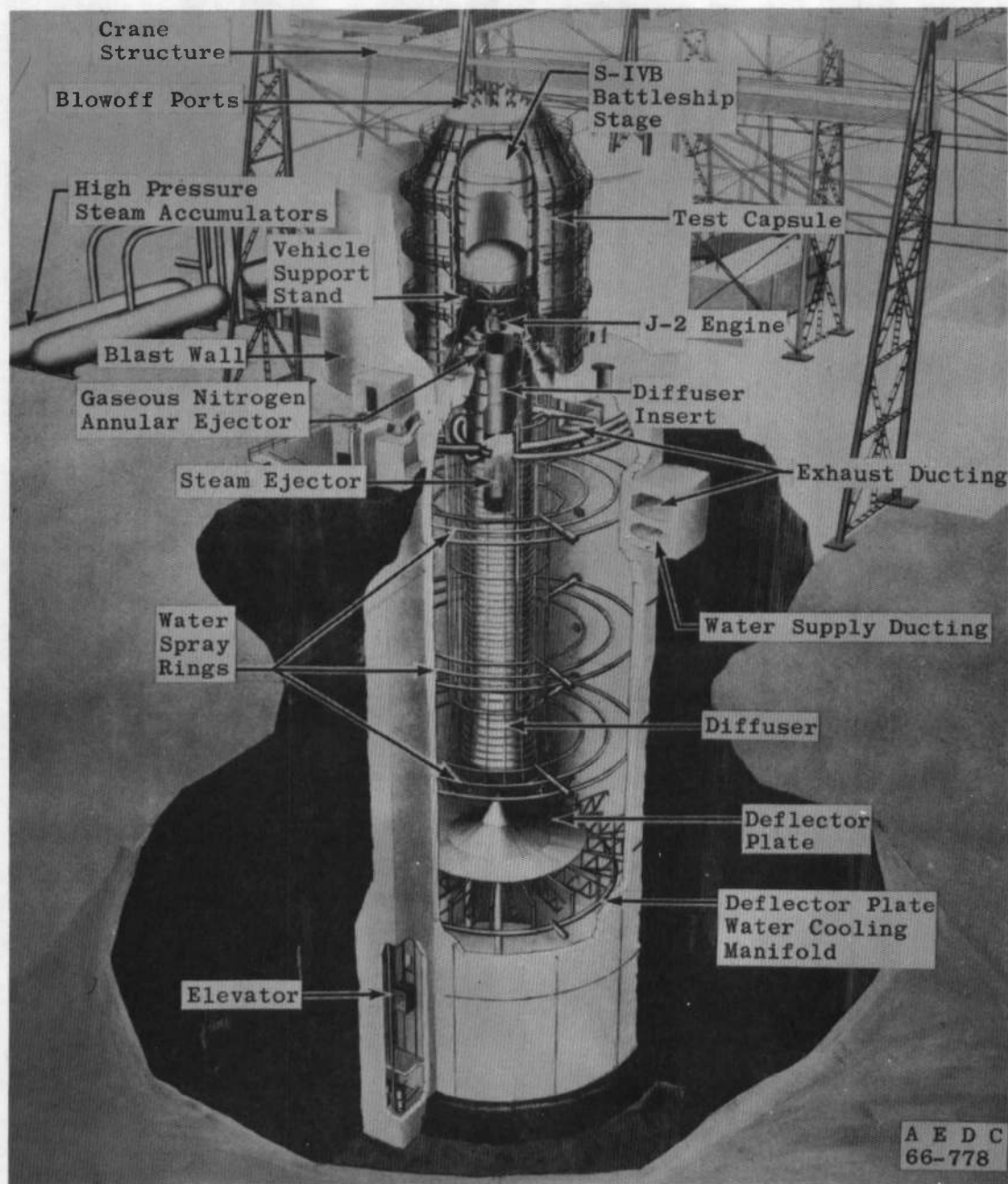
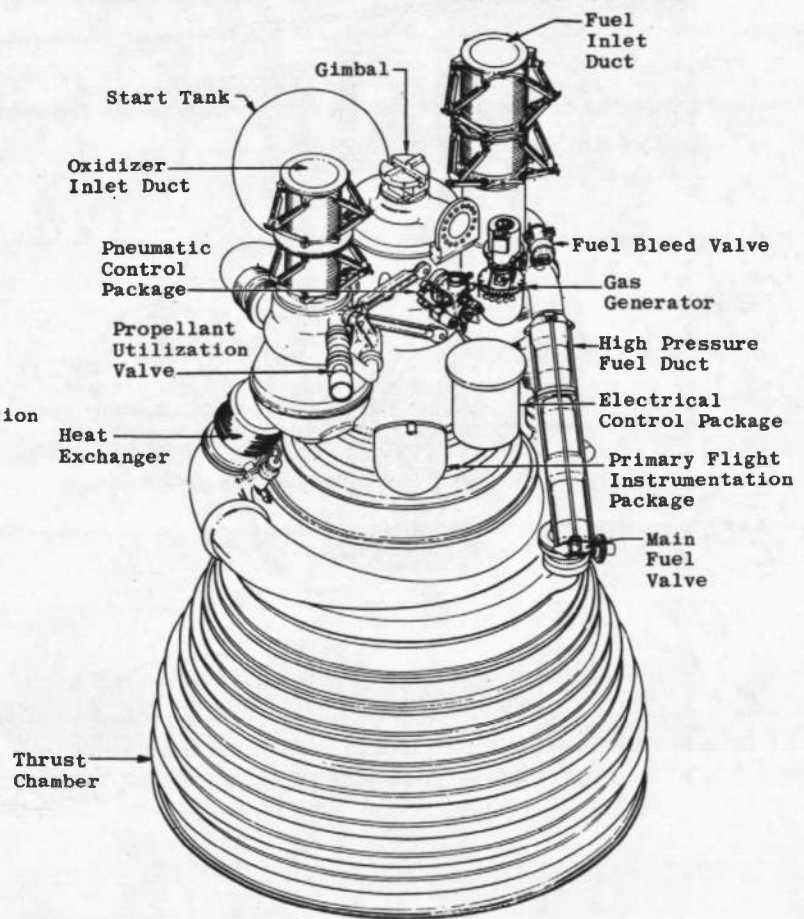
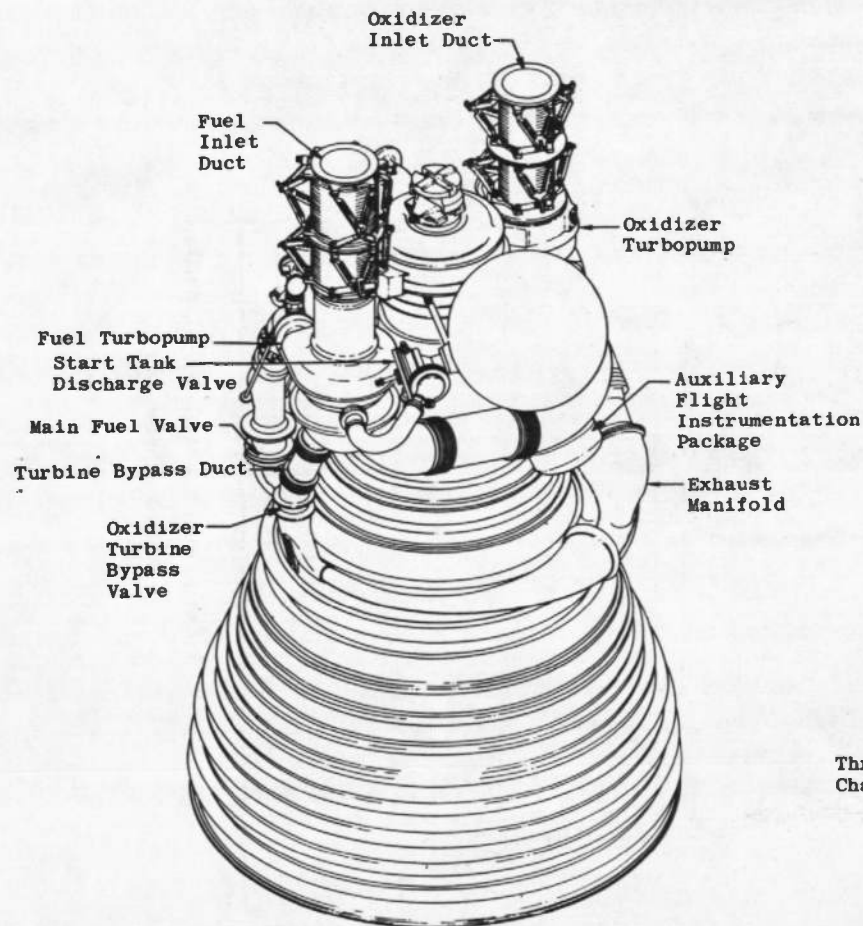
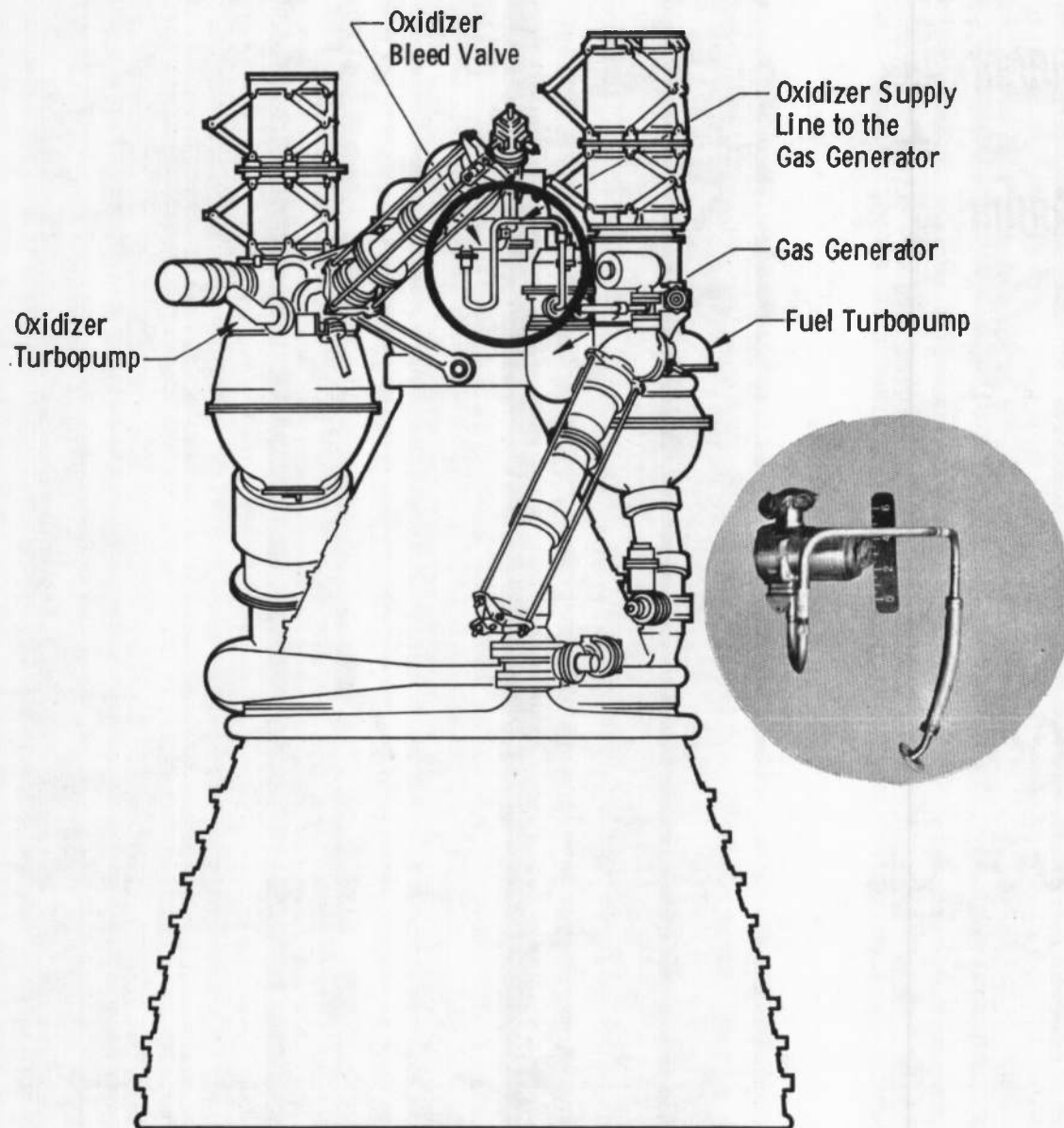


Fig. 2 Test Cell J-4, Artist's Conception

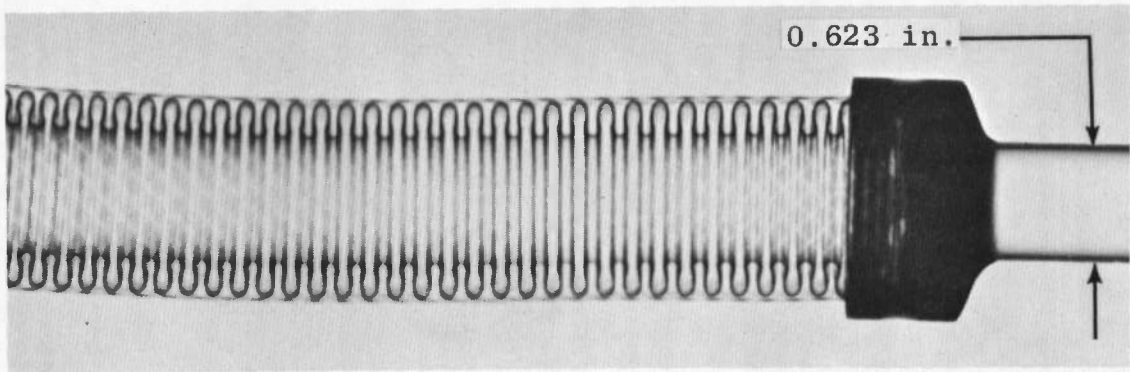


a. Major Engine Components  
Fig. 3 Engine Details

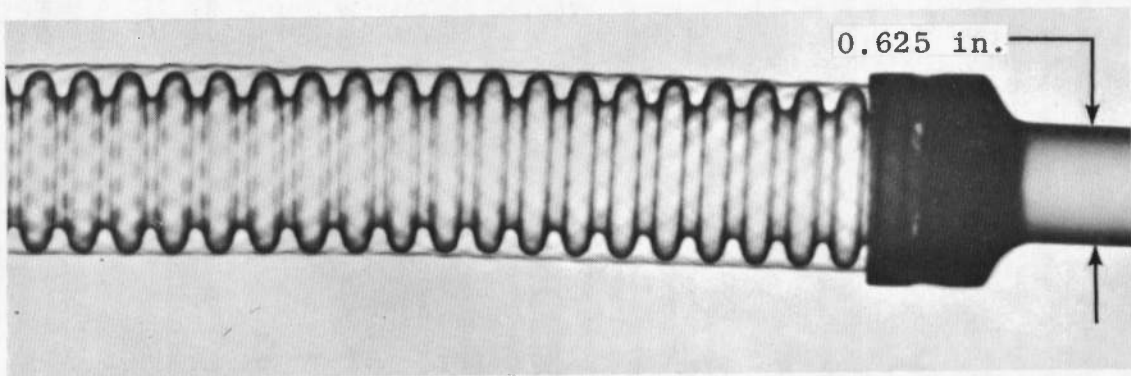


b. Gas Generator Oxidizer Supply Line Detail  
Fig. 3 Continued





c. Gas Generator Oxidizer Supply Line Assembly, Anaconda (P/N 408710, S/N 3729063)



d. Gas Generator Oxidizer Supply Line Assembly, Avica (P/N NA5-260113, S/N 045)

Fig. 3 Concluded

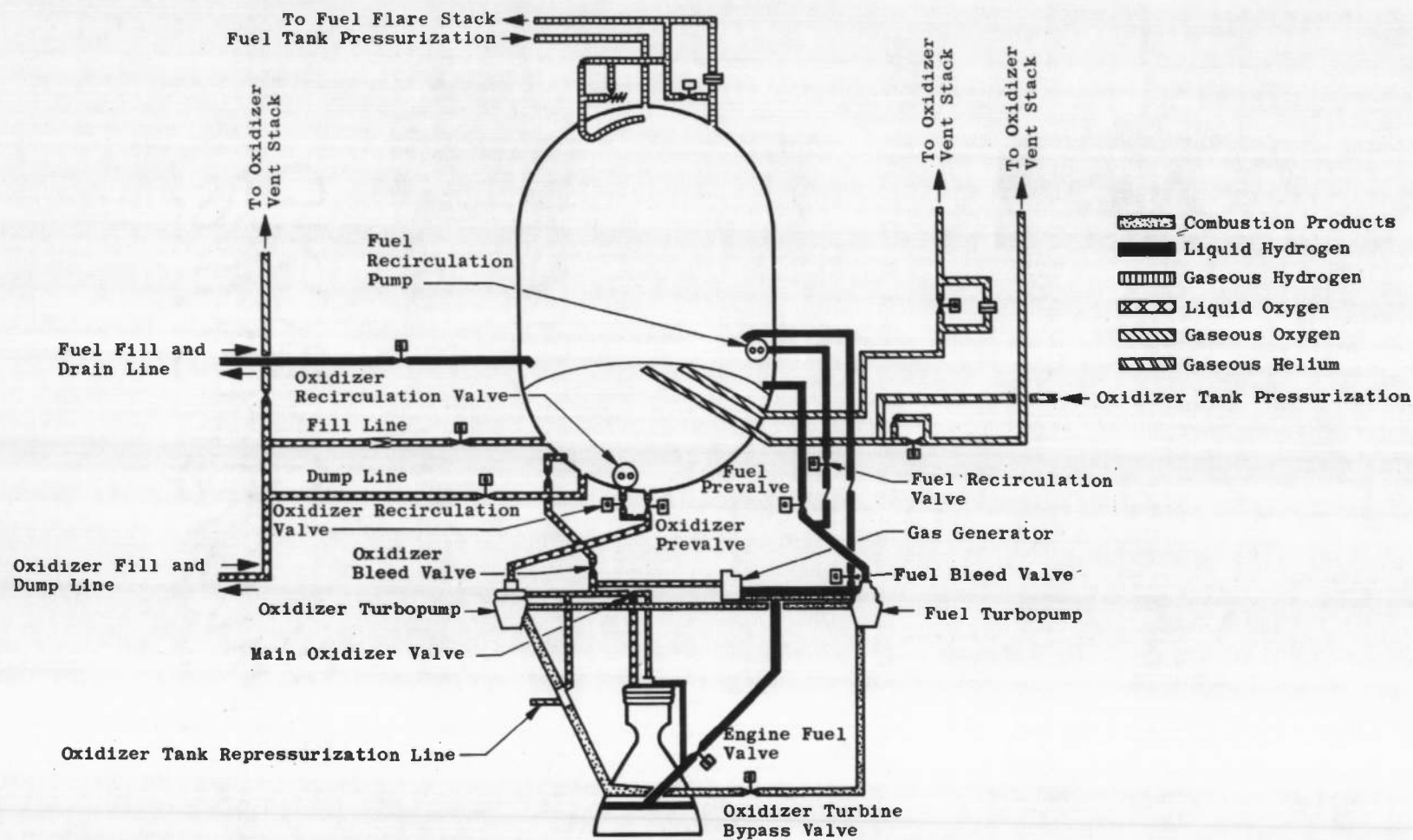


Fig. 4 S-IVB Battleship Stage/J-2 Engine Schematic



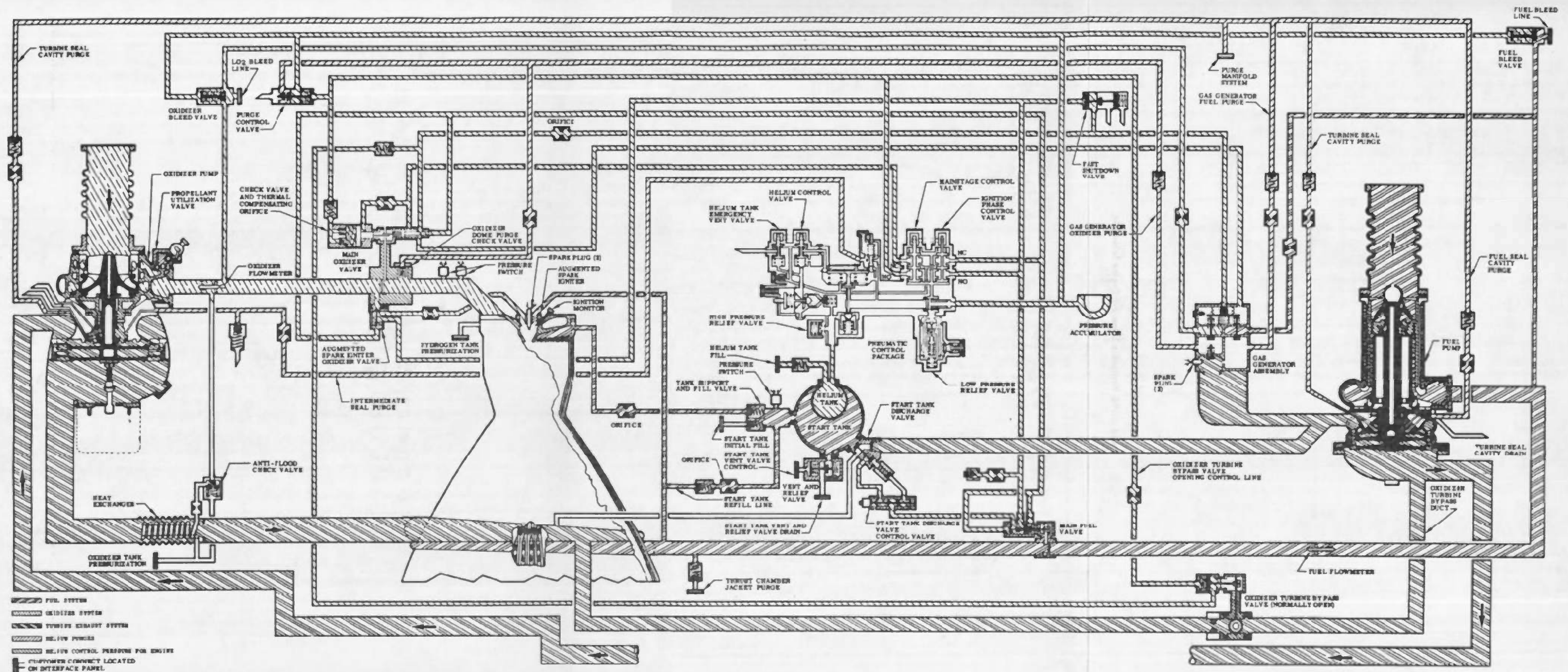


Fig. 5 Engine Schematic

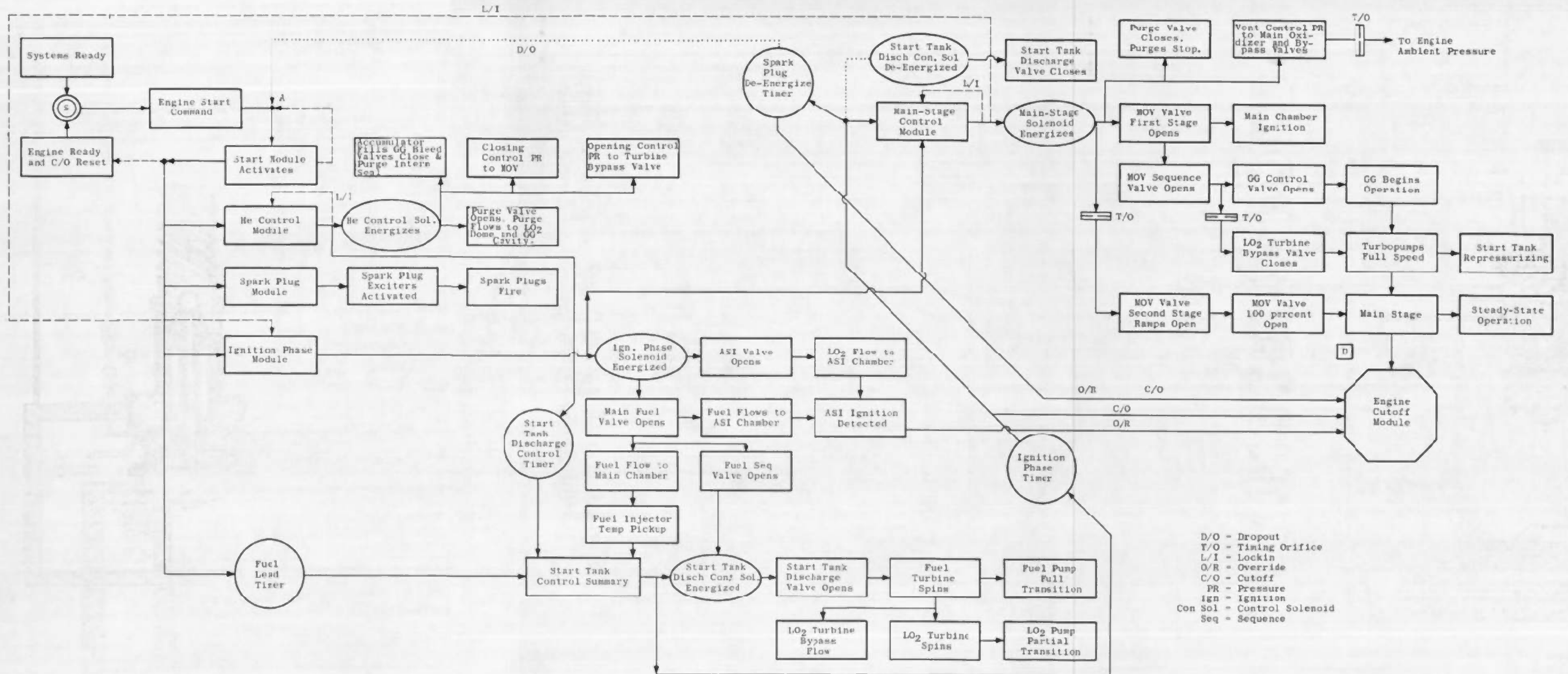
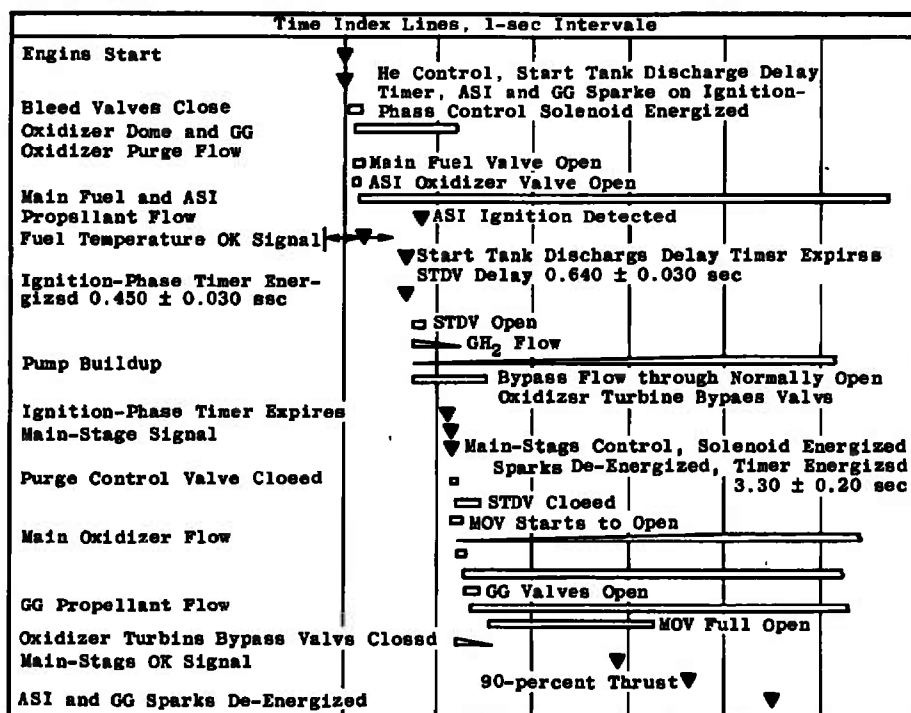
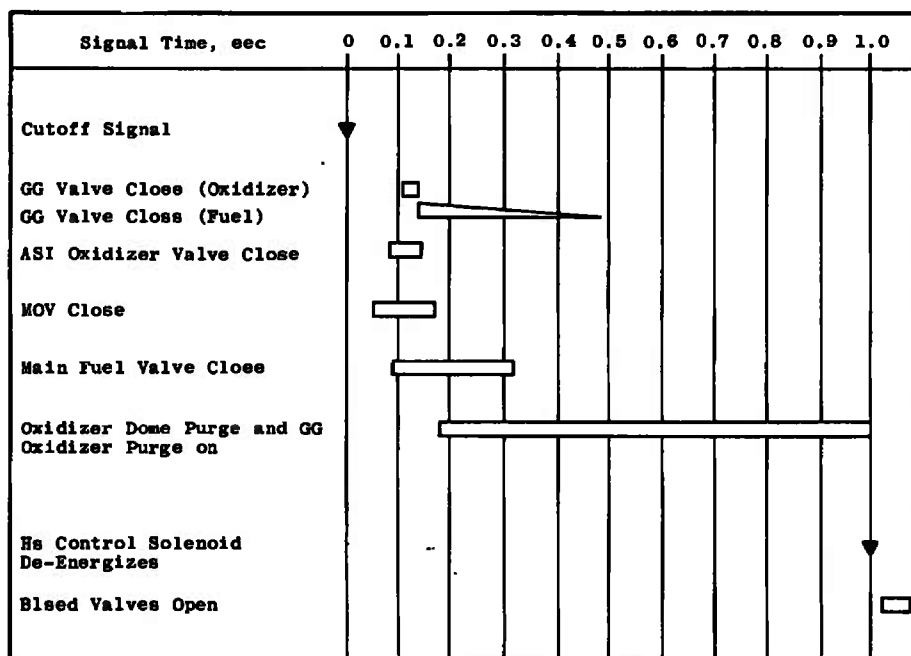


Fig. 6 Engine Start Logic Schematic

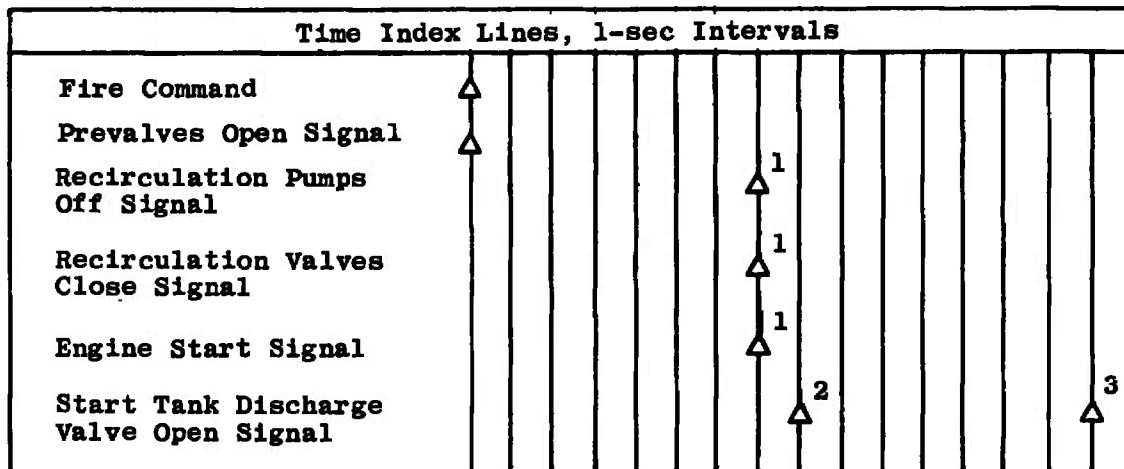


a. Start Sequence



b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence

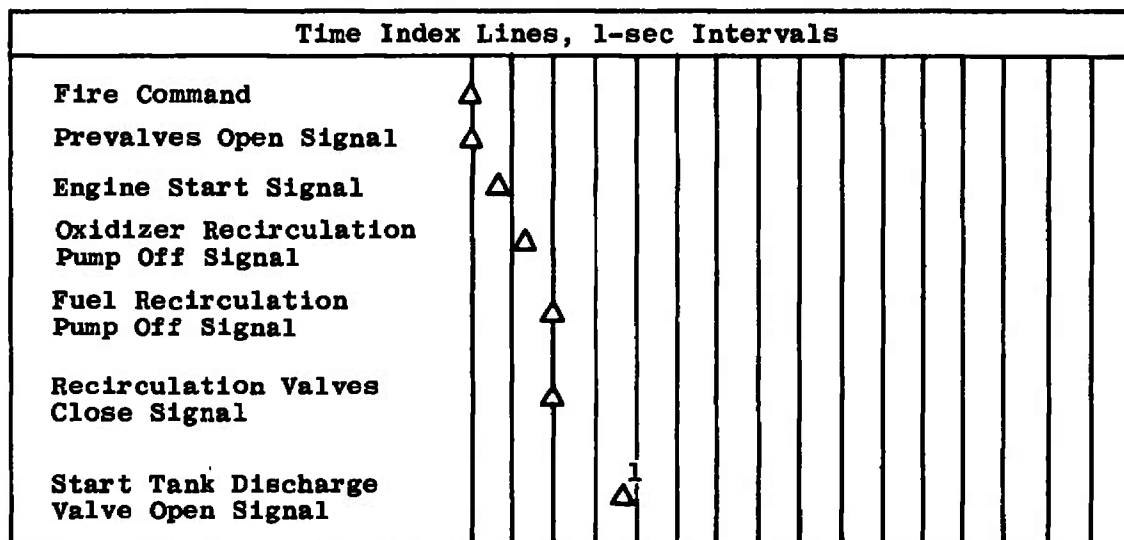


<sup>1</sup>Nominal Occurrence Time (Function of Prevalves Opening Time)

<sup>2</sup>One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)

<sup>3</sup>Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

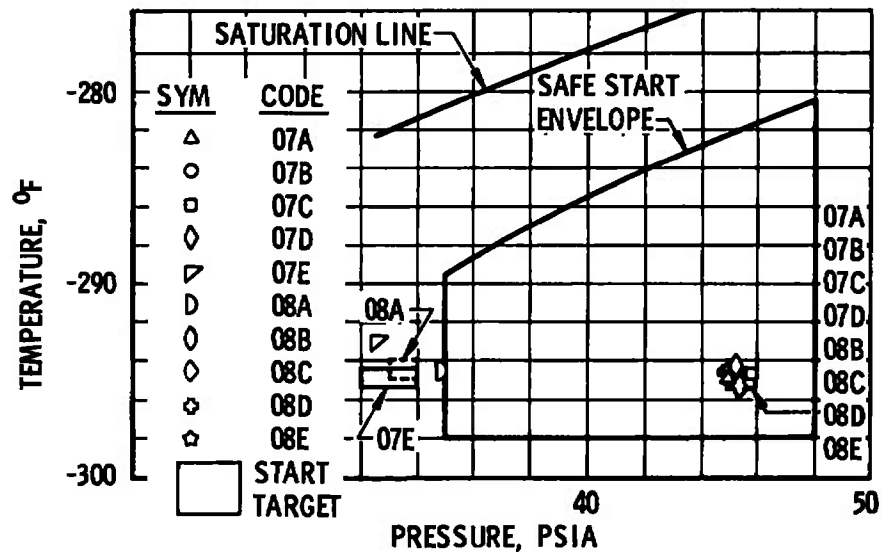
c. "Normal" Start Sequence



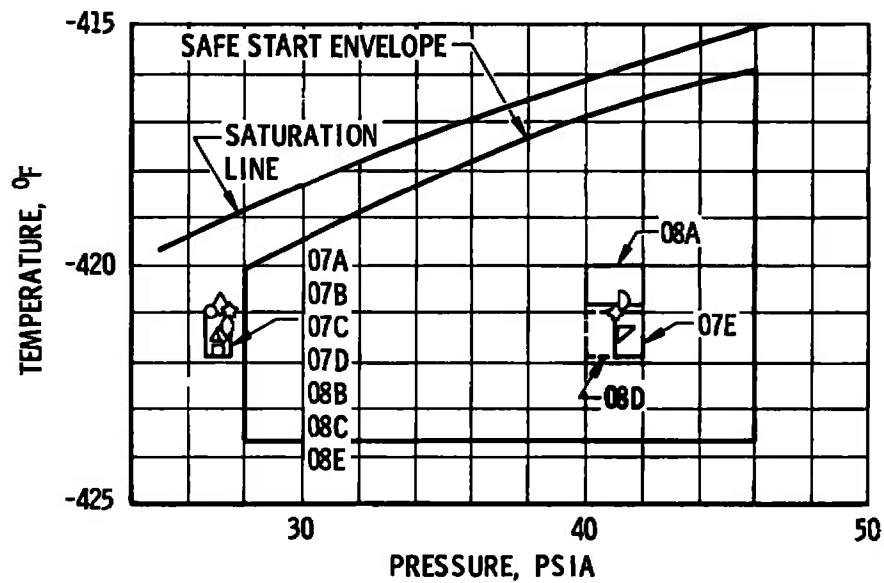
<sup>1</sup>Three-sec Fuel Lead (S-IVB/S-V First Burn)

d. "Auxiliary" Start Sequence

Fig. 7 Concluded



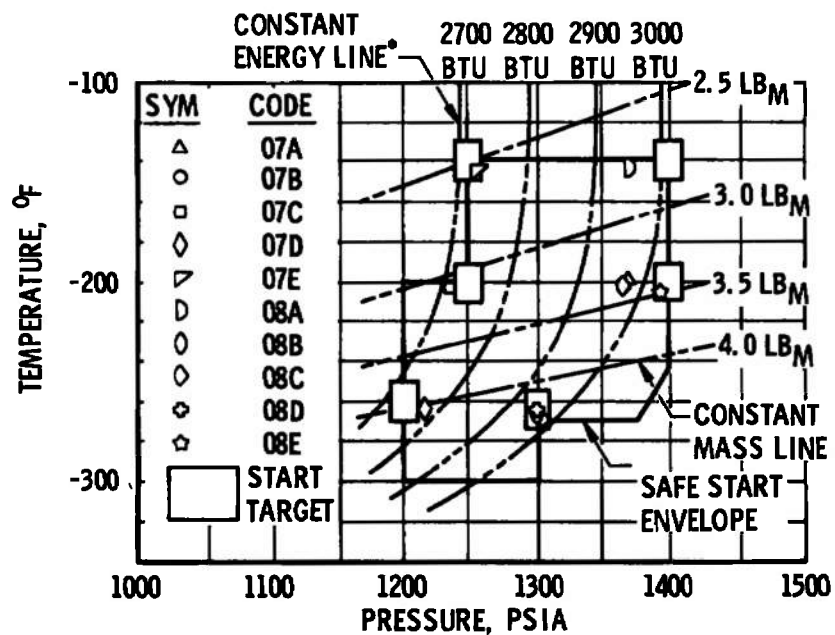
a. Oxidizer Pump Inlet



b. Fuel Pump Inlet

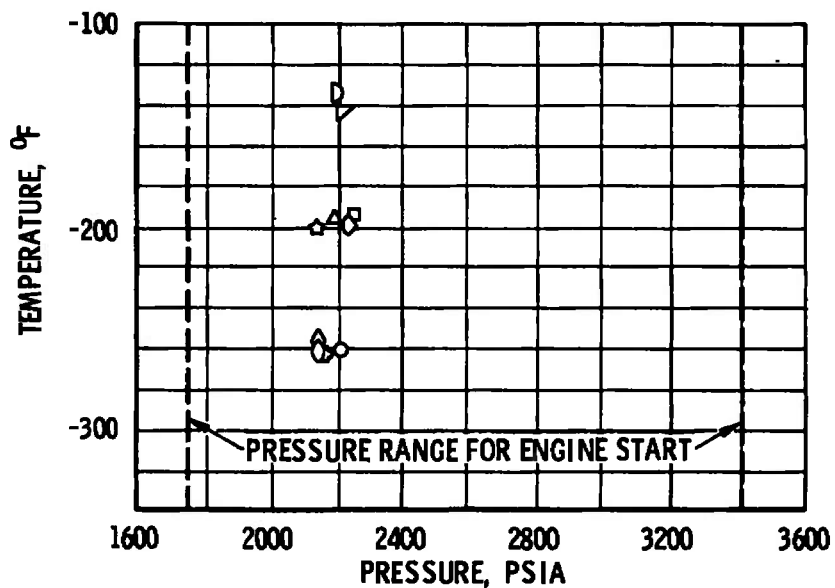
Fig. 8 Engine Start Conditions for the Pump Inlets, Start Tank, and Helium Tank





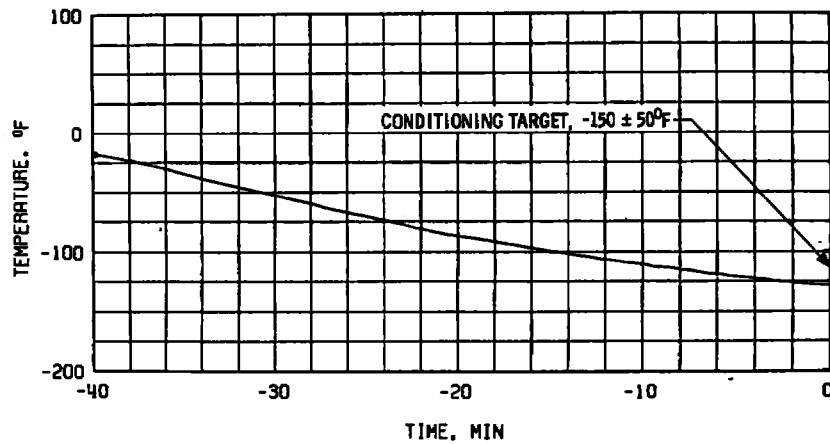
\*CALCULATED FROM  
"TABLE OF THERMAL  
PROPERTIES OF GASES,"  
NATIONAL BUREAU OF  
STANDARDS CIRCULAR  
564, NOVEMBER 1965.

c. Start Tank

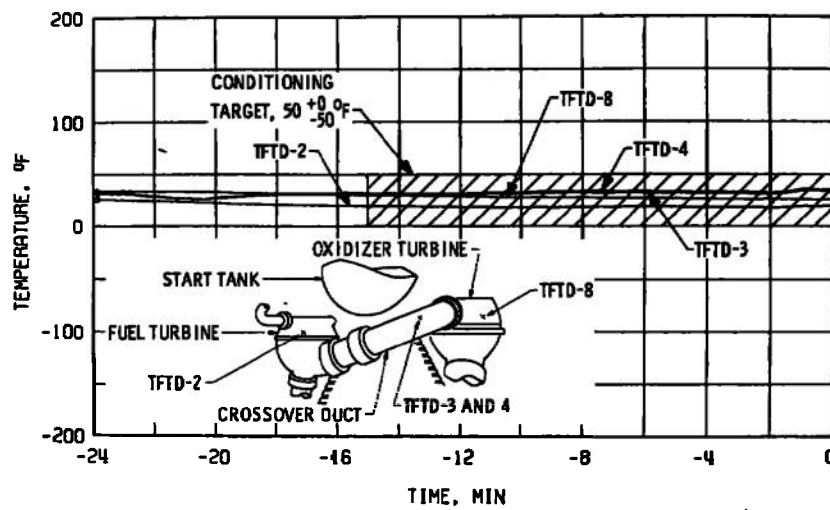


d. Helium Tank

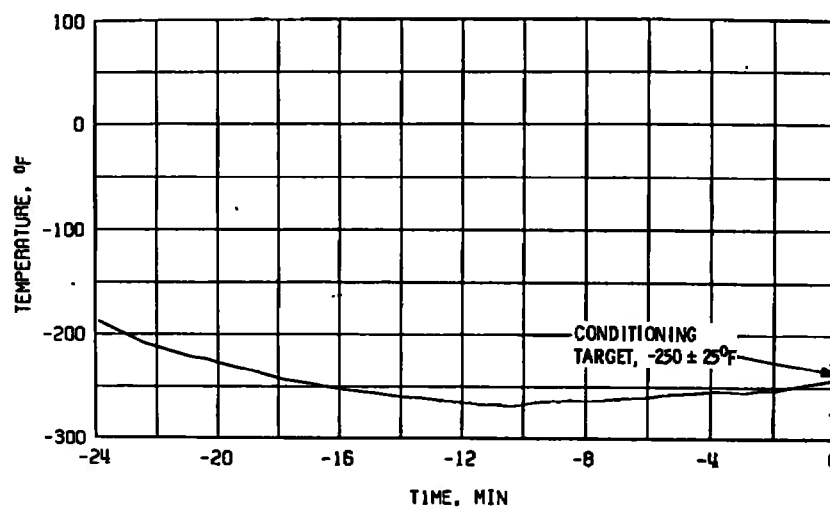
Fig. 8 Concluded



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

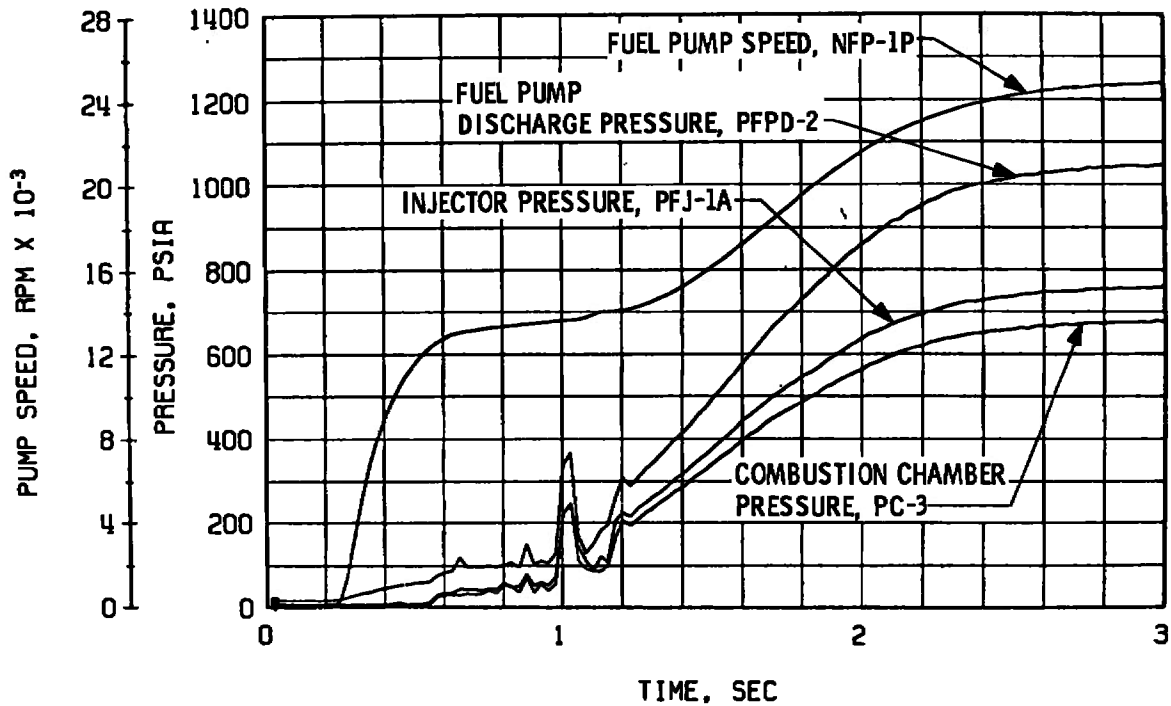


b. Crossover Duct, TTFD

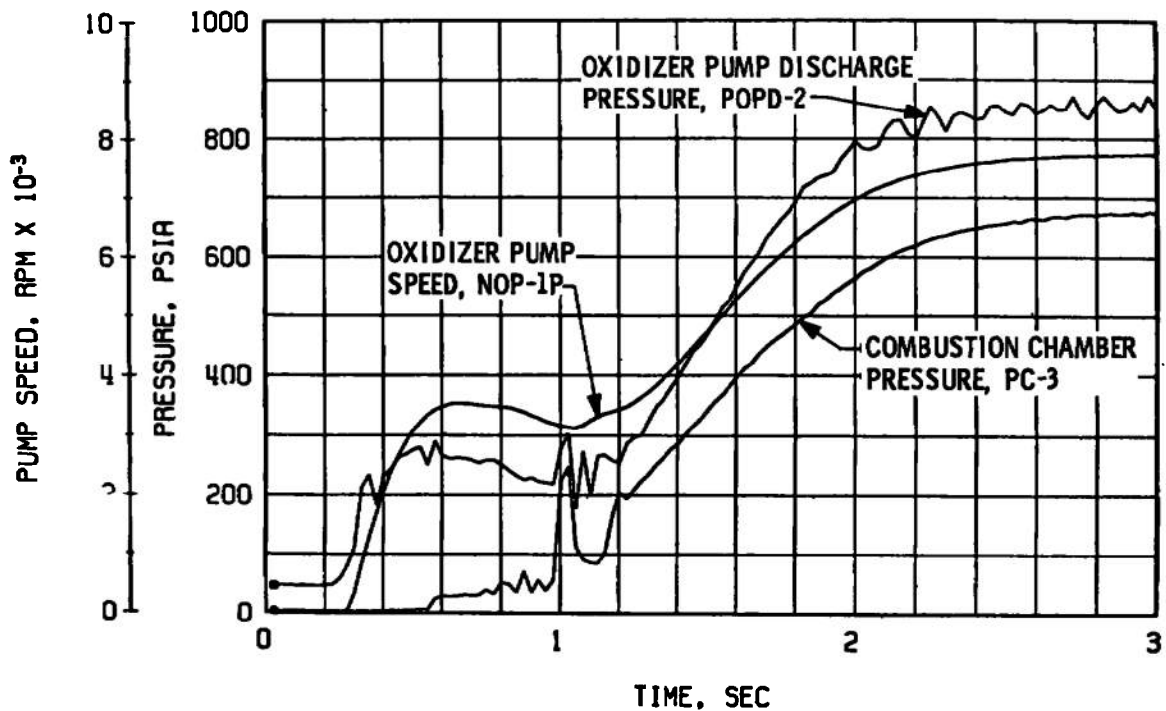


c. Thrust Chamber Throat, TTC-1P

Fig. 9 Thermal Conditioning History of Engine Components, Firing 07A



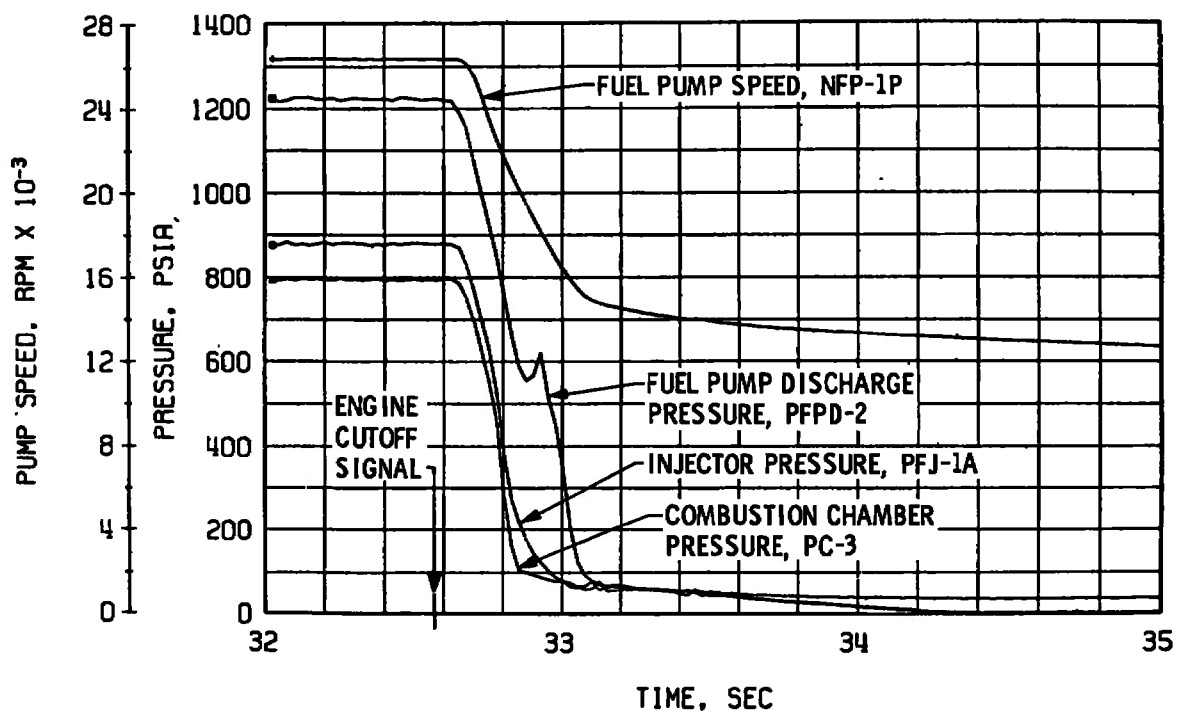
a. Thrust Chamber Fuel System, Start



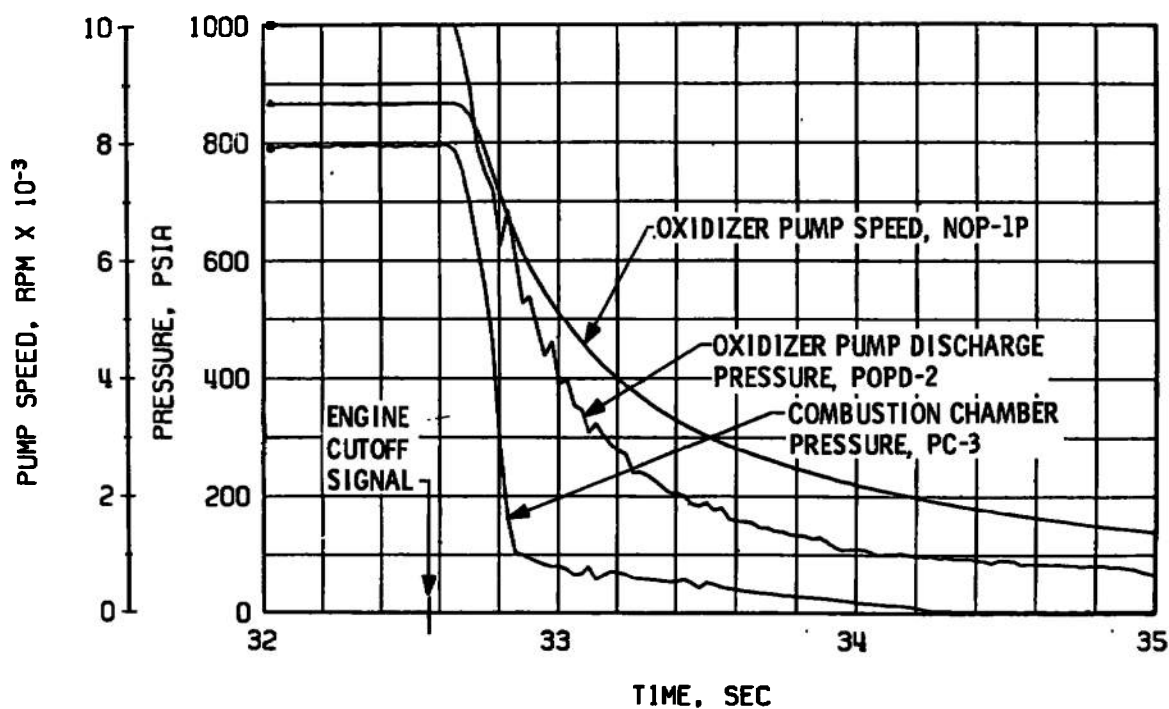
b. Thrust Chamber Oxidizer System, Start

Fig. 10 Engine Transient Operation, Firing 07A



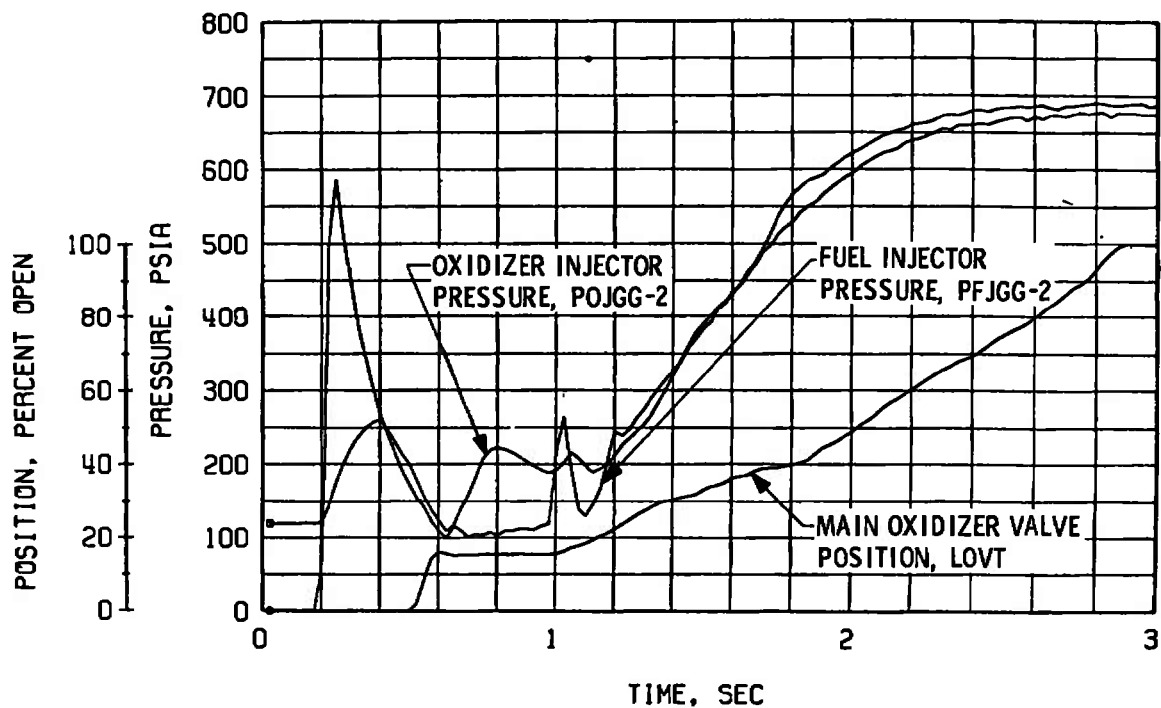


c. Thrust Chamber Fuel System, Shutdown

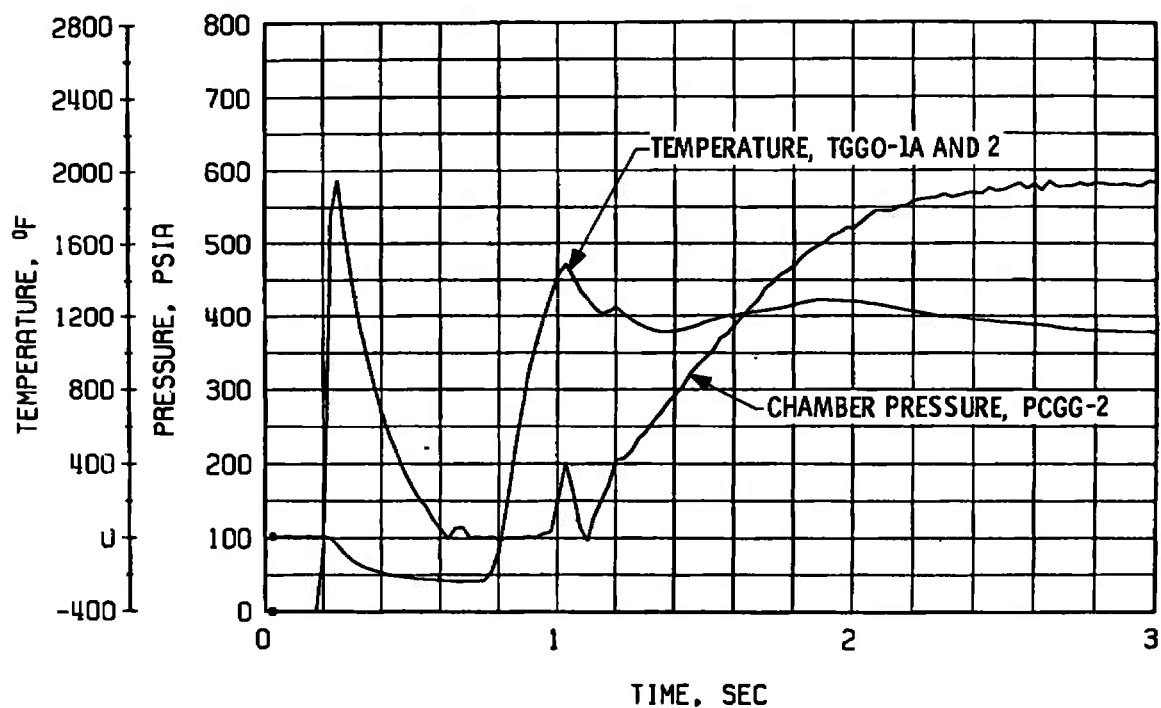


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 10 Continued

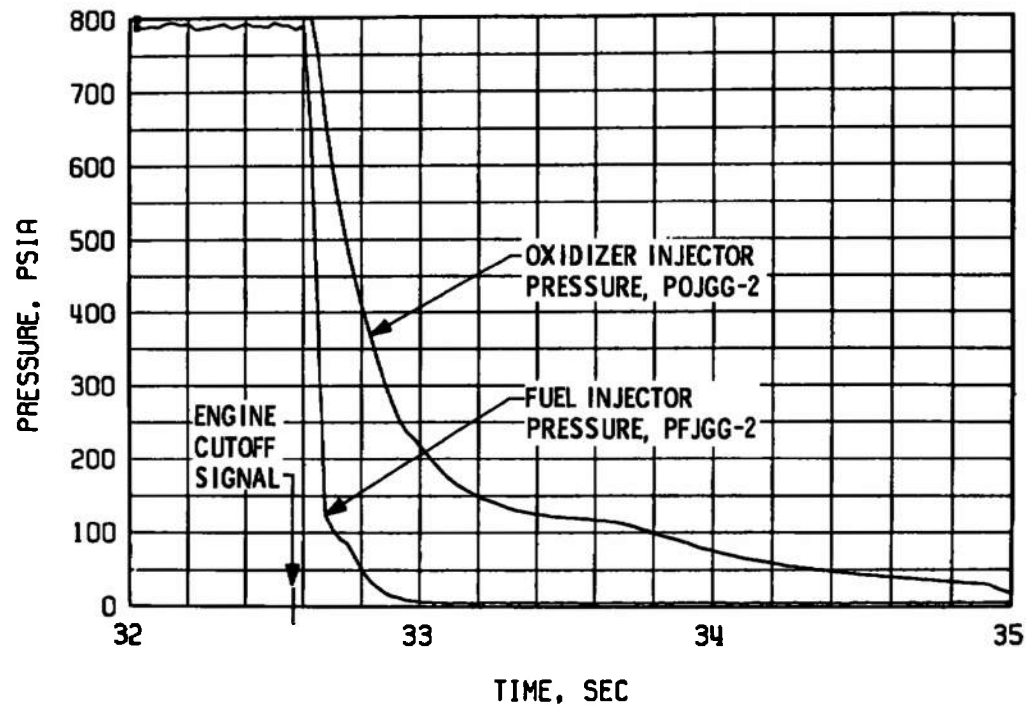


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

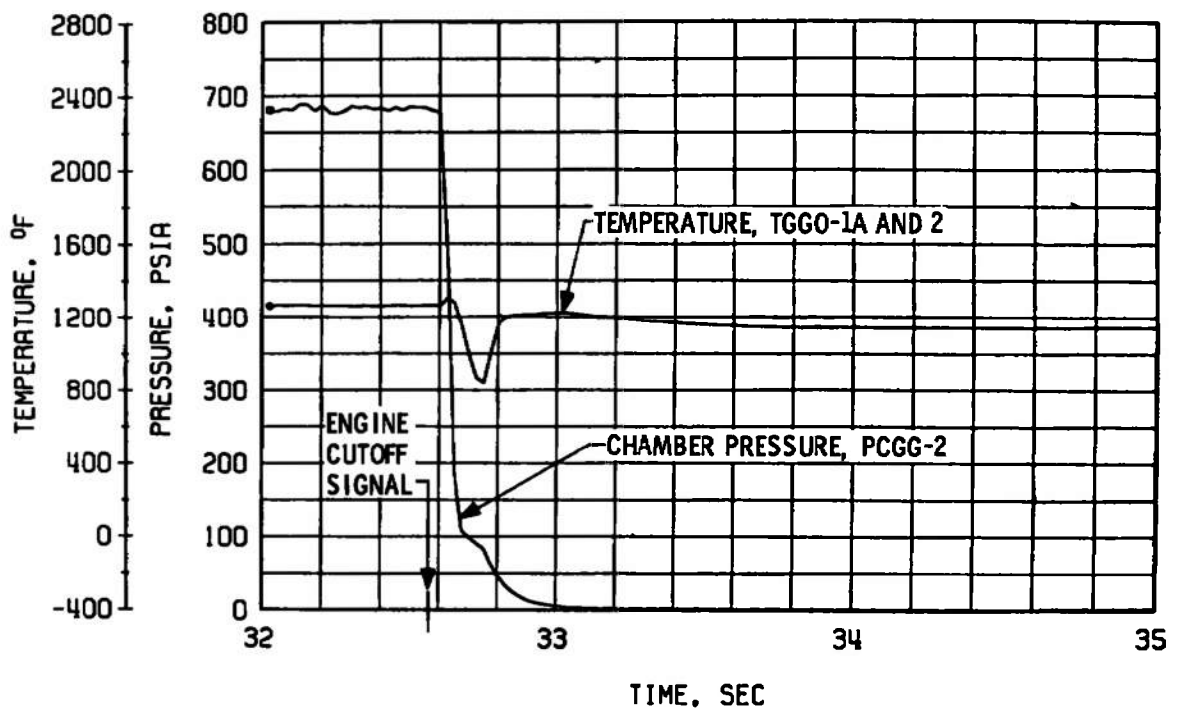


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 10 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 10 Concluded

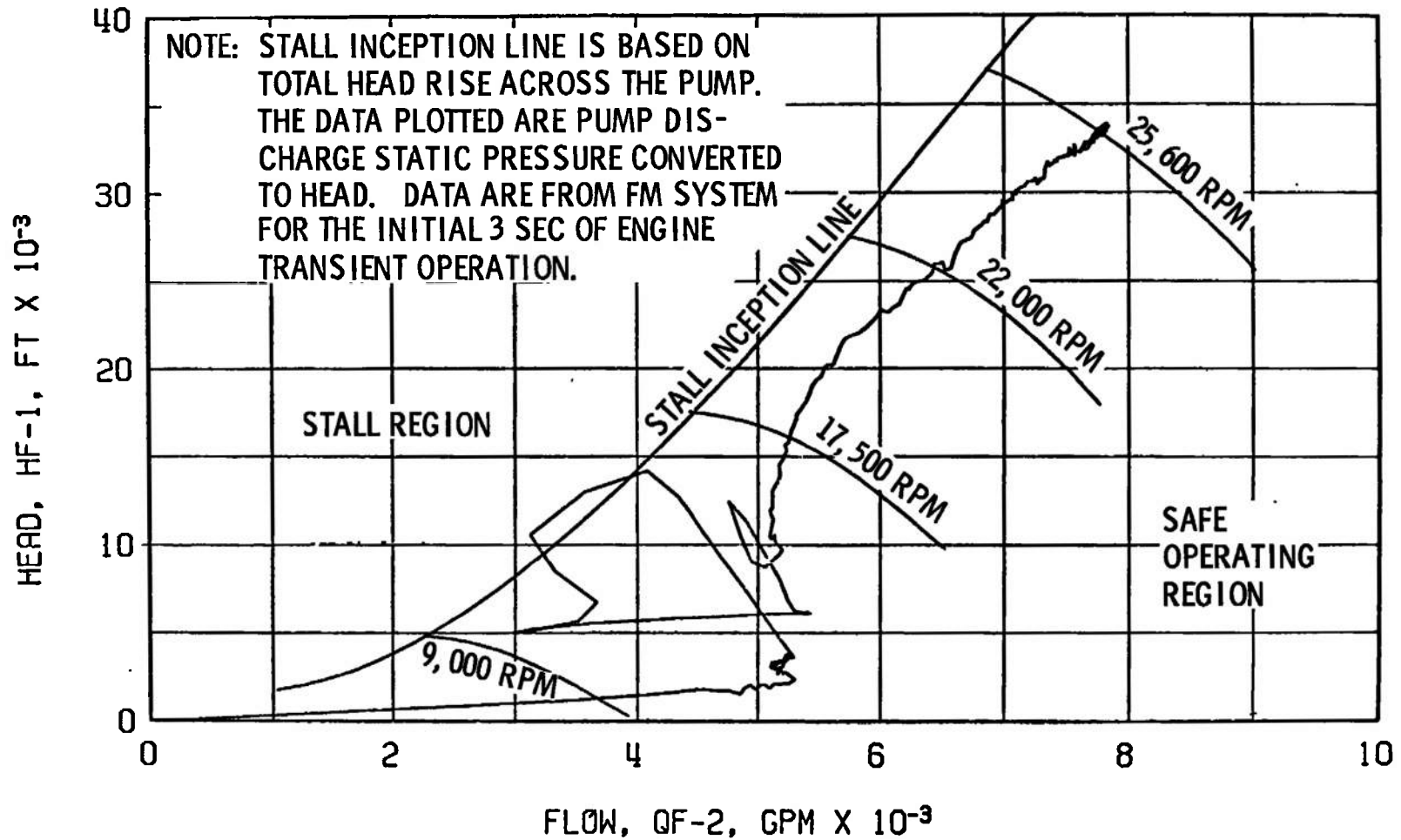


Fig. 11 Fuel Pump Start Transient Performance, Firing 07A

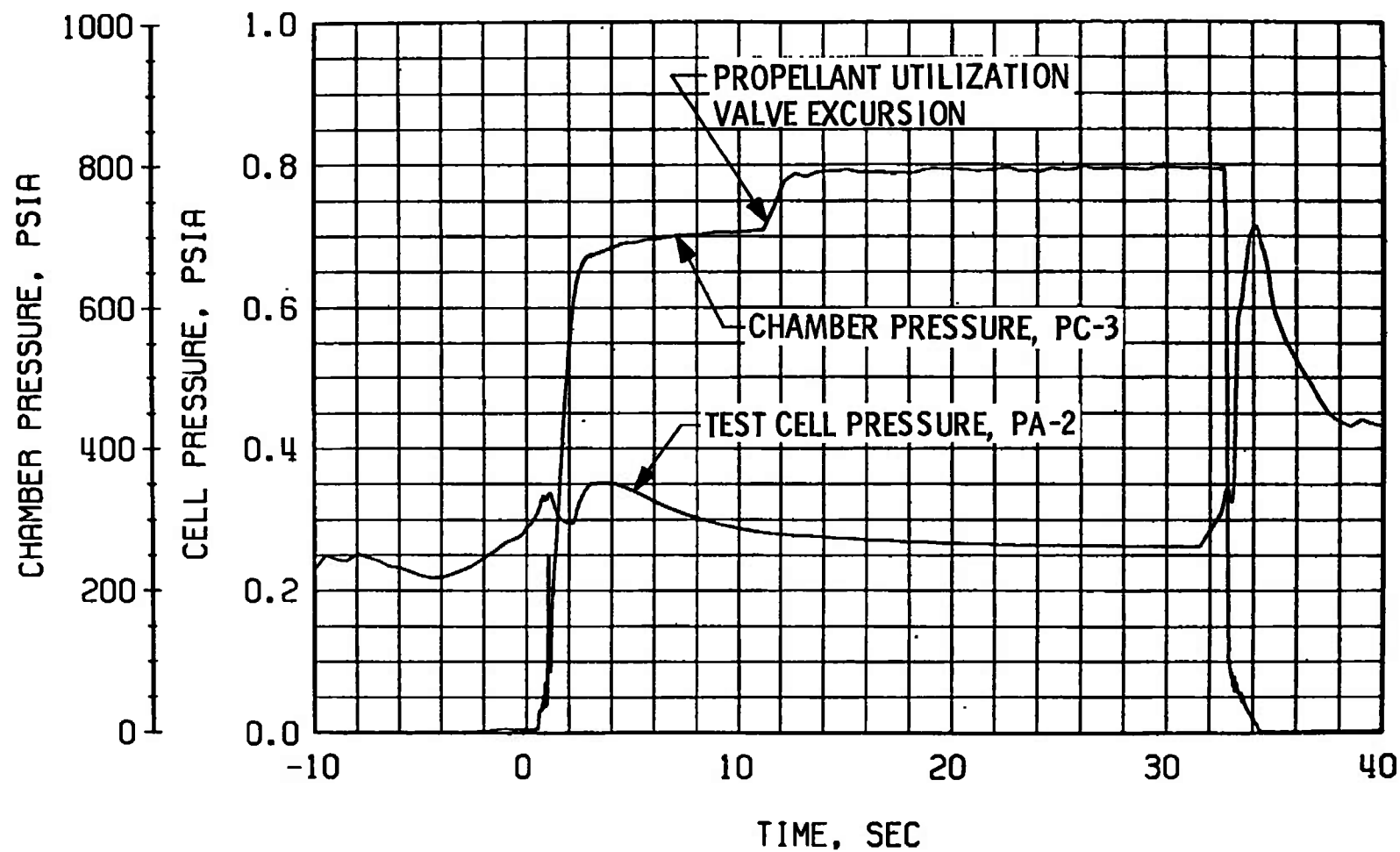
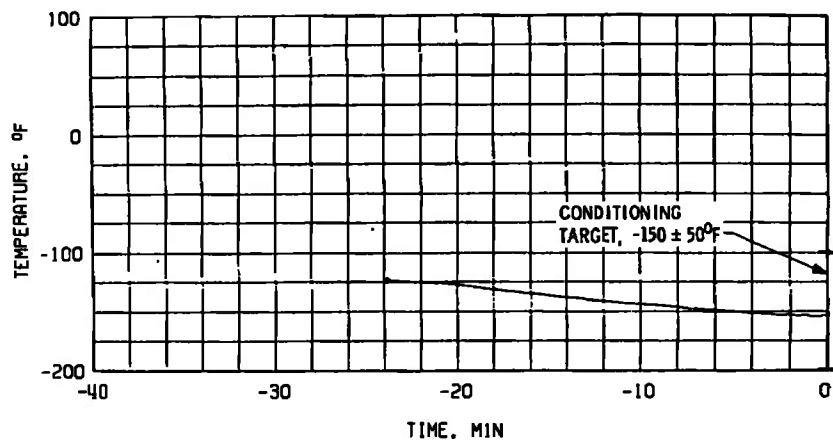
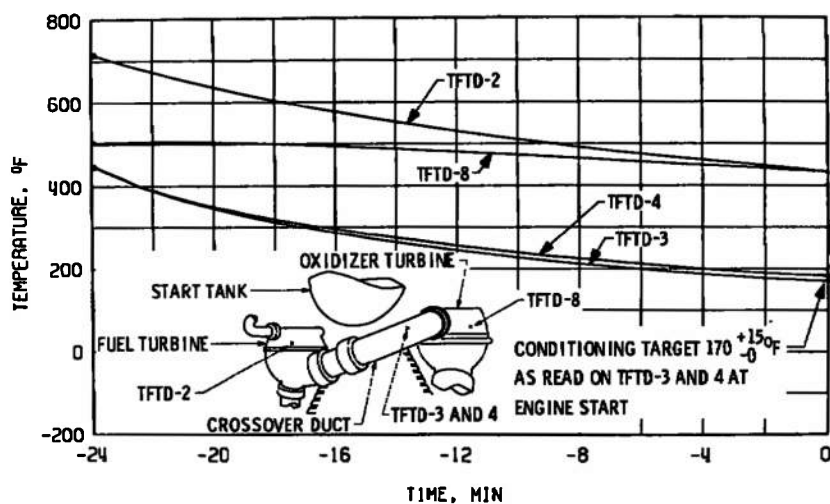


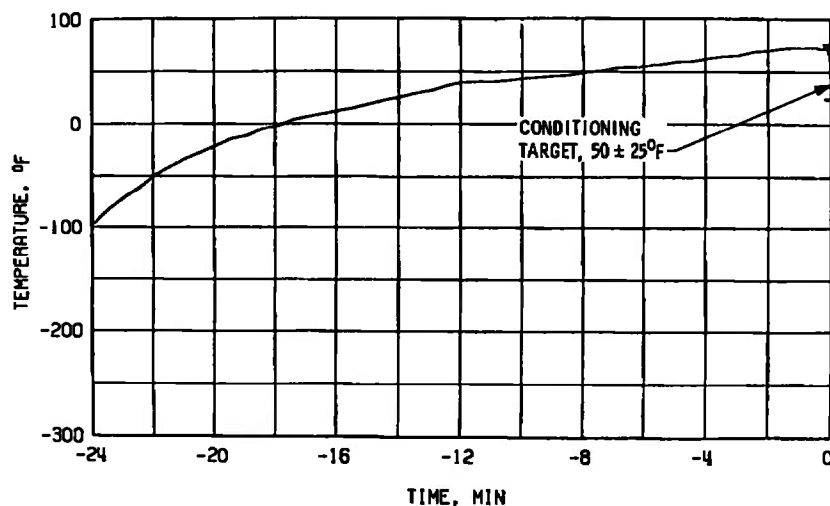
Fig. 12 Engine Ambient and Combustion Chamber Pressure, Firing 07A



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

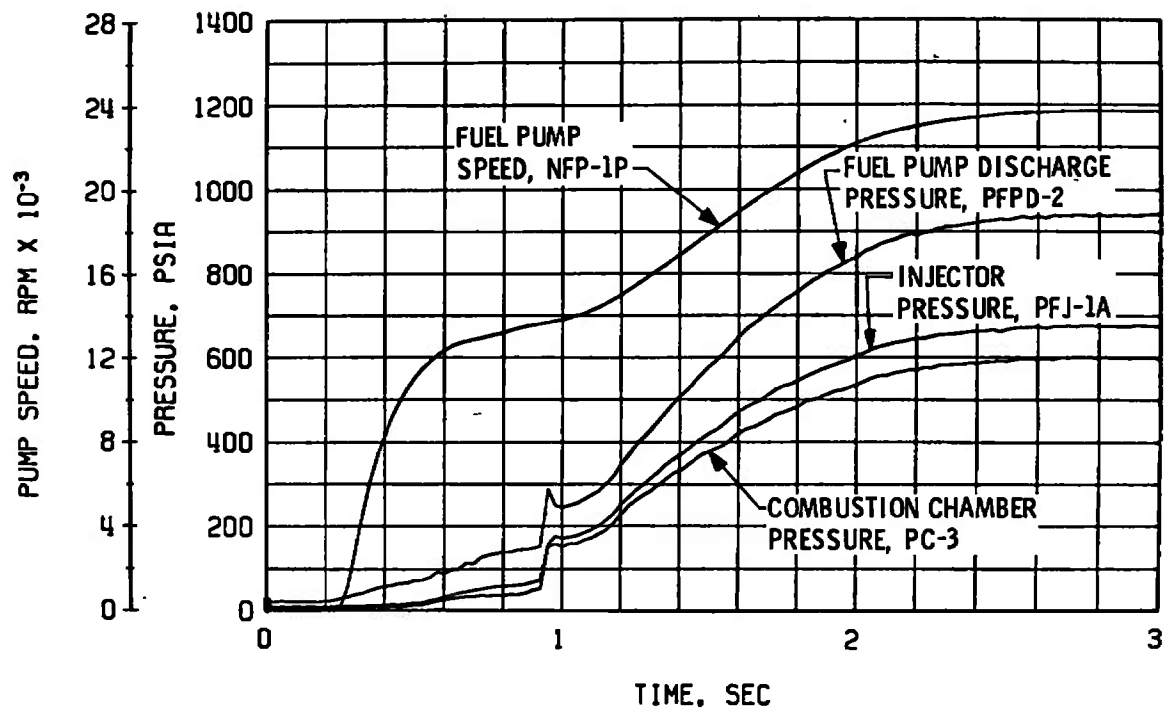


b. Crossover Duct, TFTD

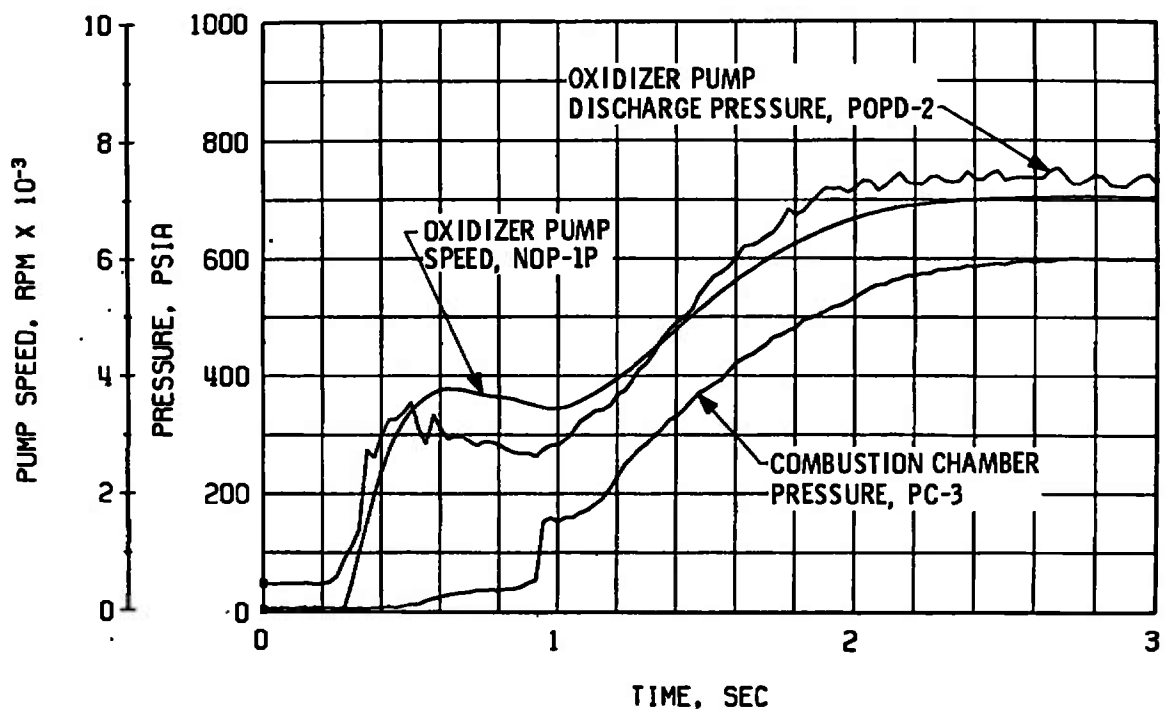


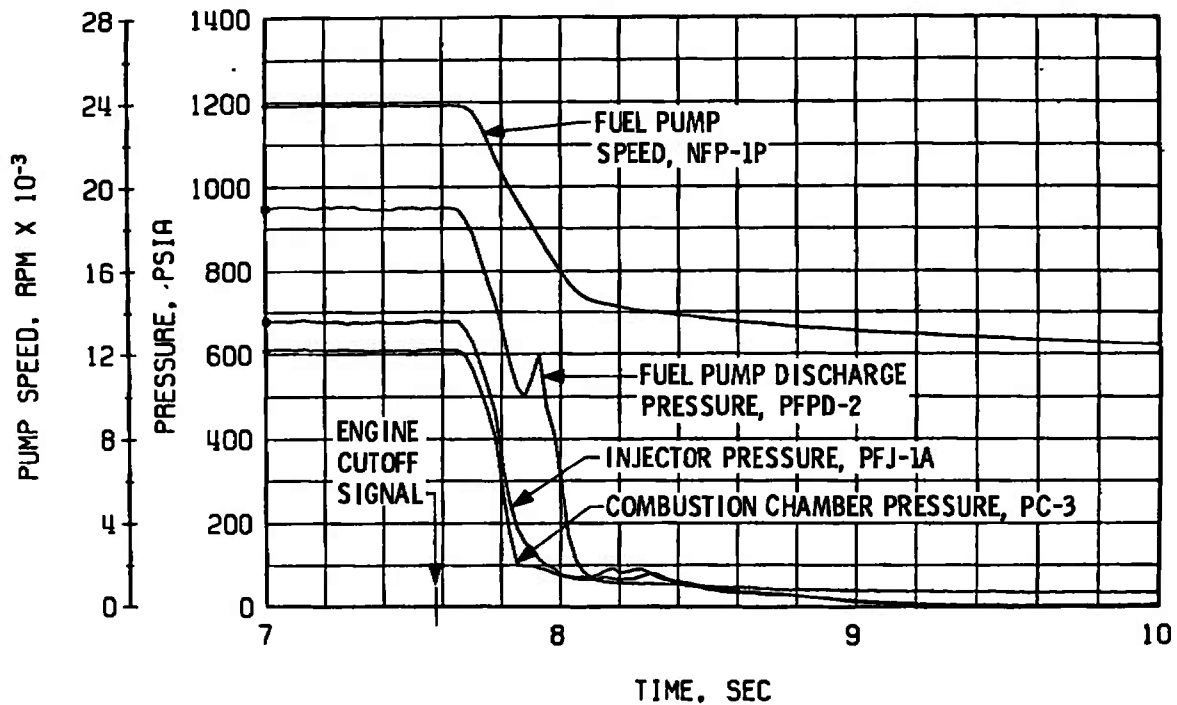
c. Thrust Chamber Throat, TTC-1P

Fig. 13 Thermal Conditioning History of Engine Components, Firing 07B

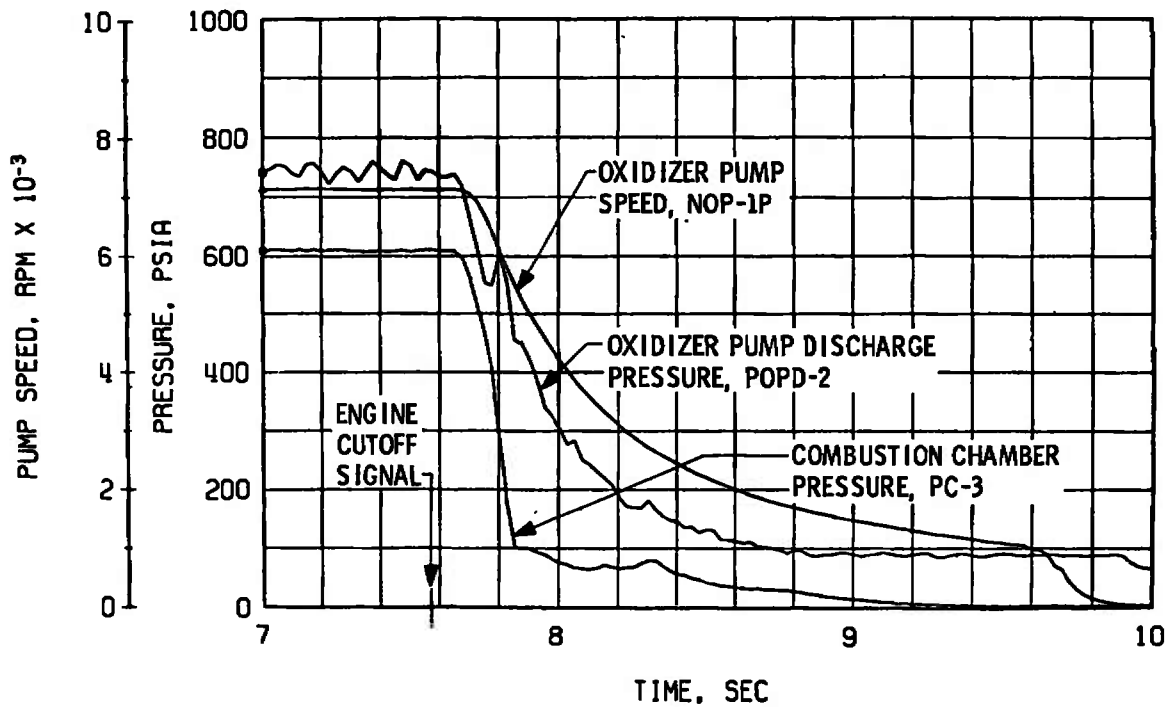


a. Thrust Chamber Fuel System, Start

b. Thrust Chamber Oxidizer System, Start  
Fig. 14 Engine Transient Operation, Firing 07B



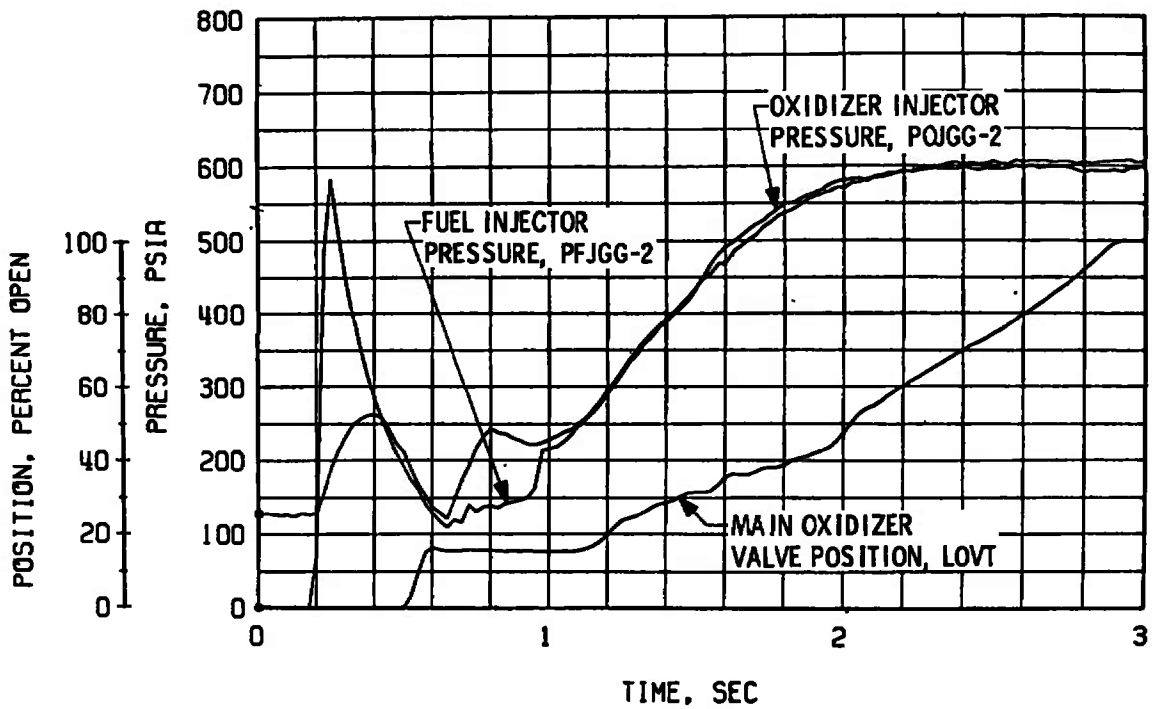
c. Thrust Chamber Fuel System, Shutdown



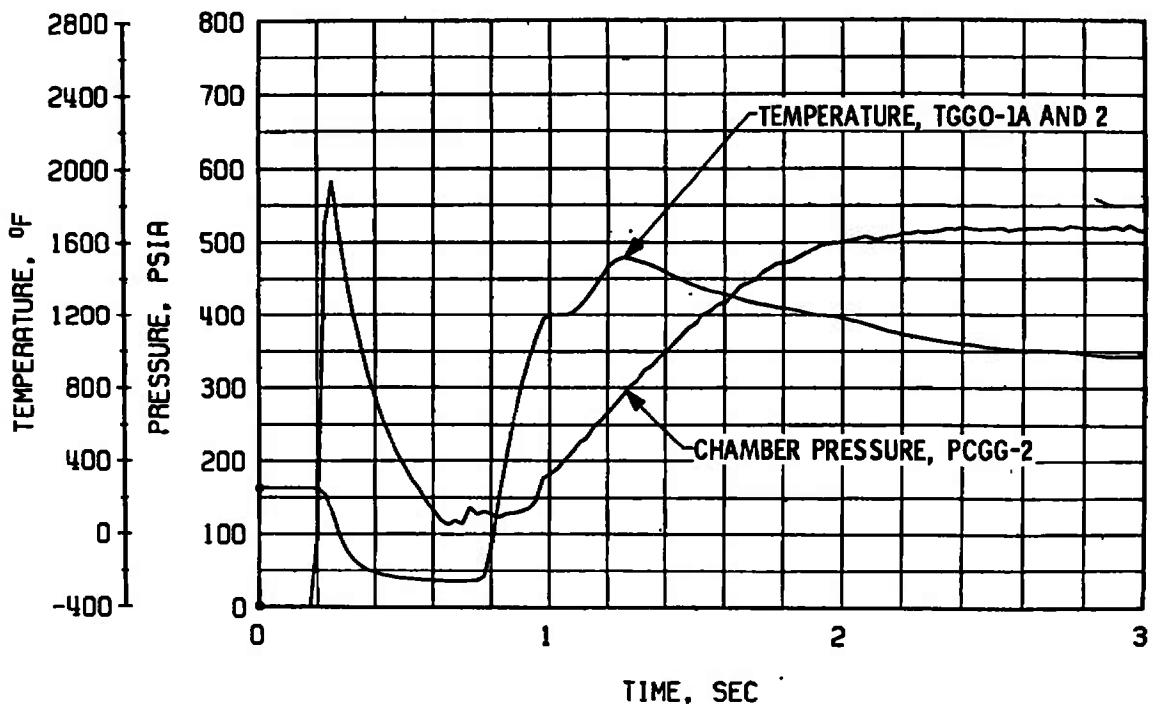
d. Thrust Chamber Oxidizer System, Shutdown

Fig. 14 Continued.





e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start



f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 14 Continued

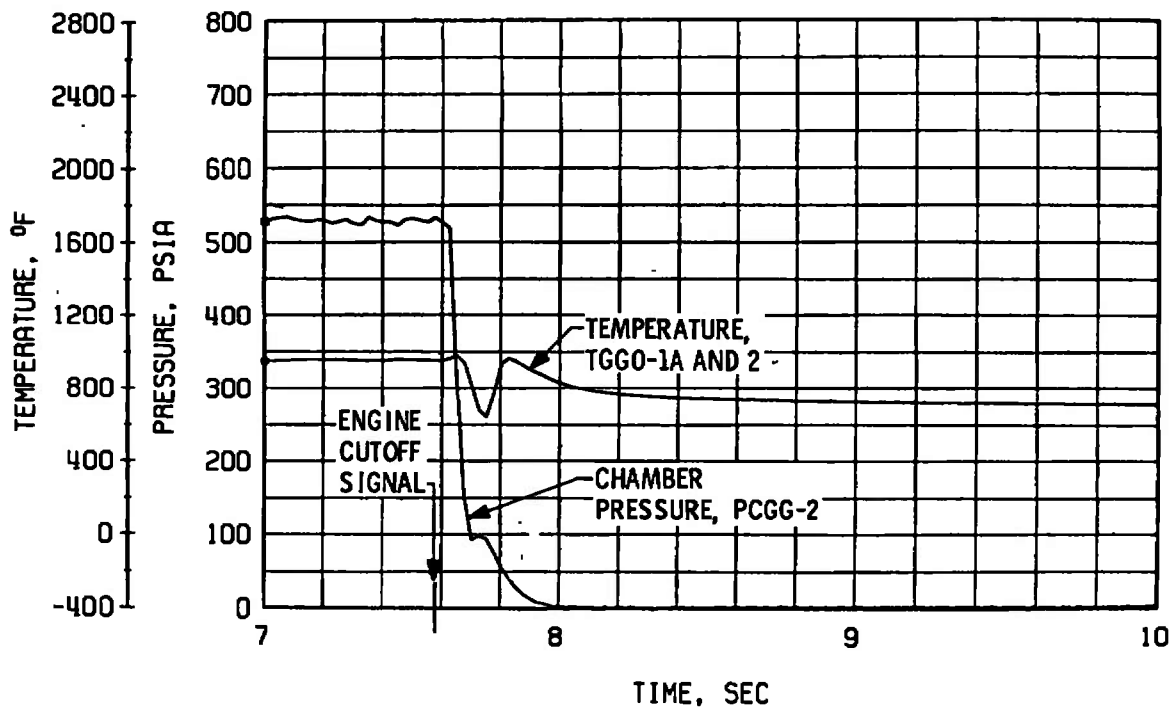
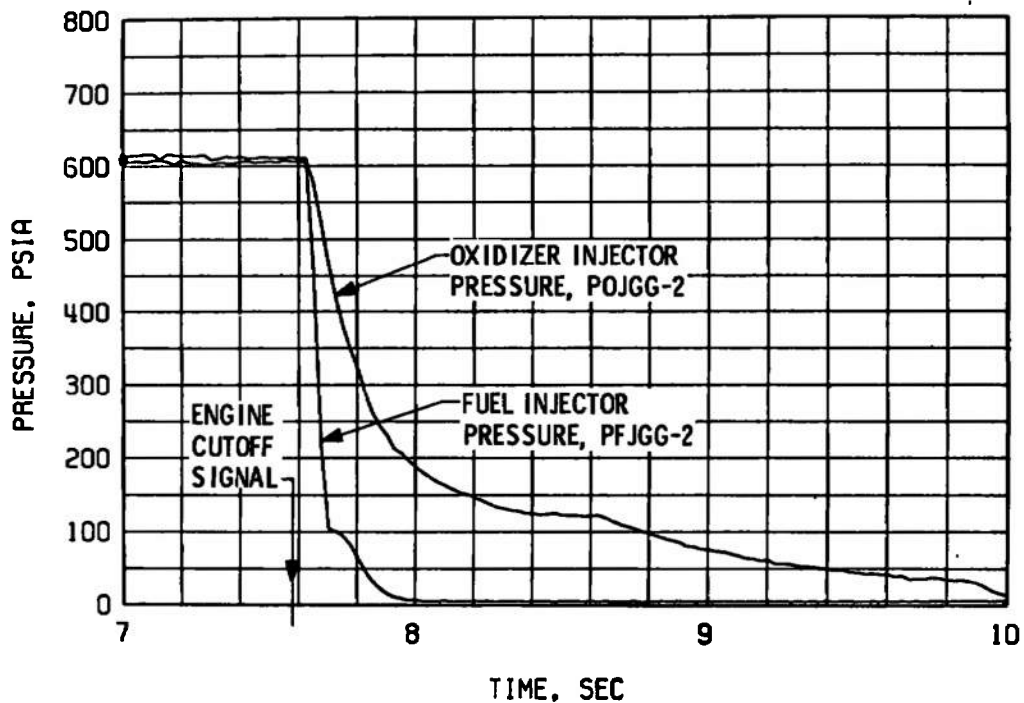


Fig. 14 Concluded

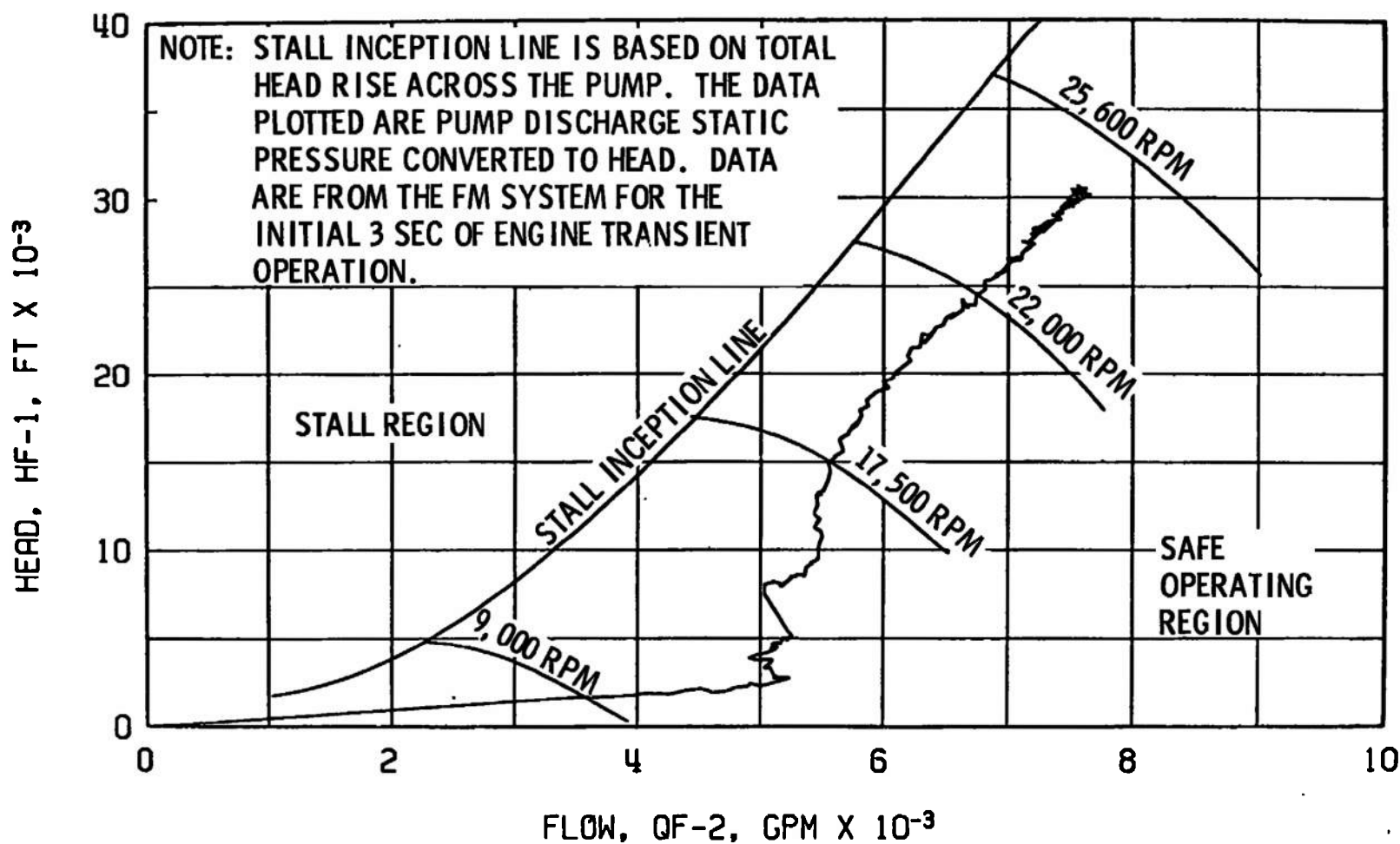


Fig. 15 Fuel Pump Start Transient Performance, Firing 07B

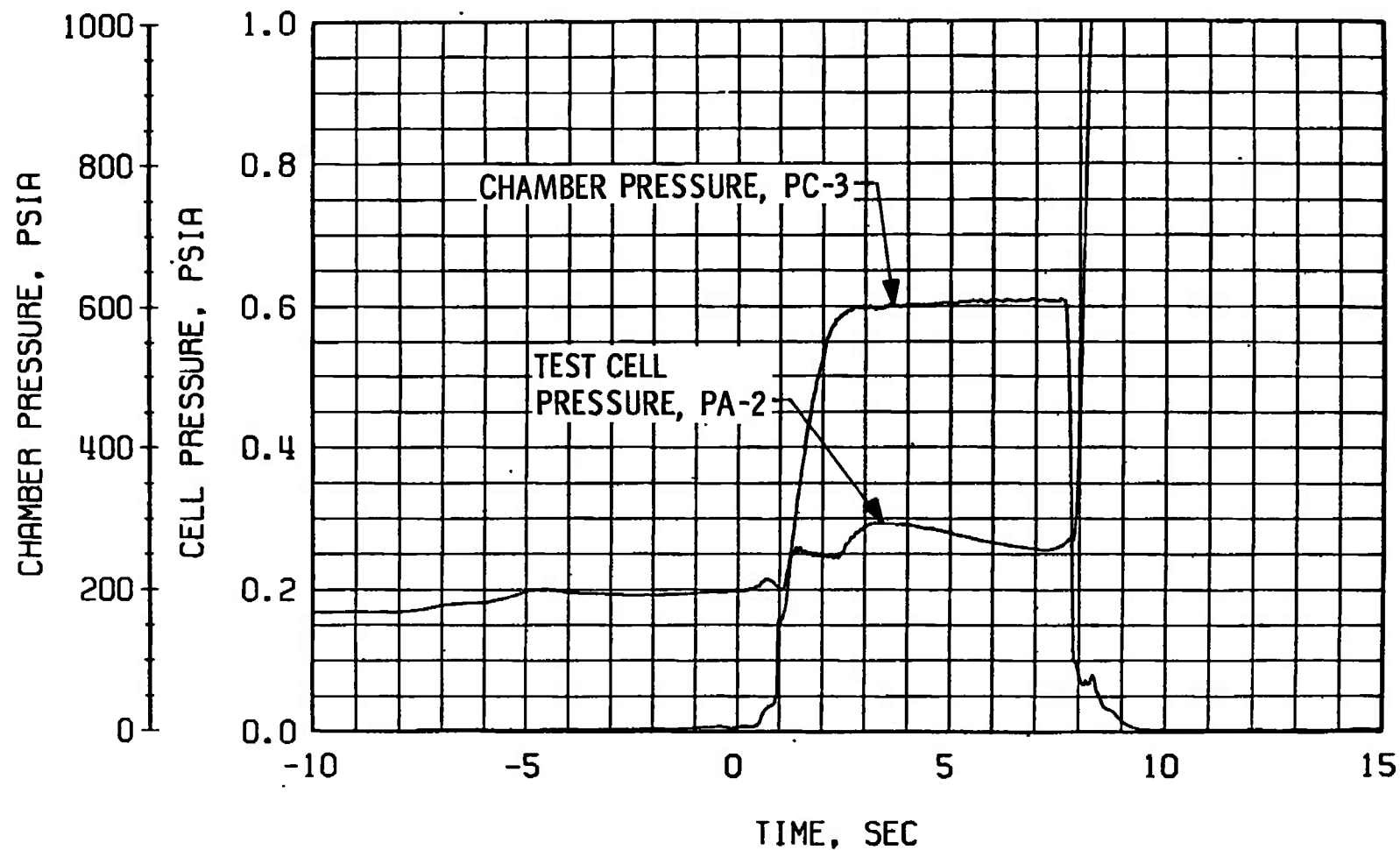
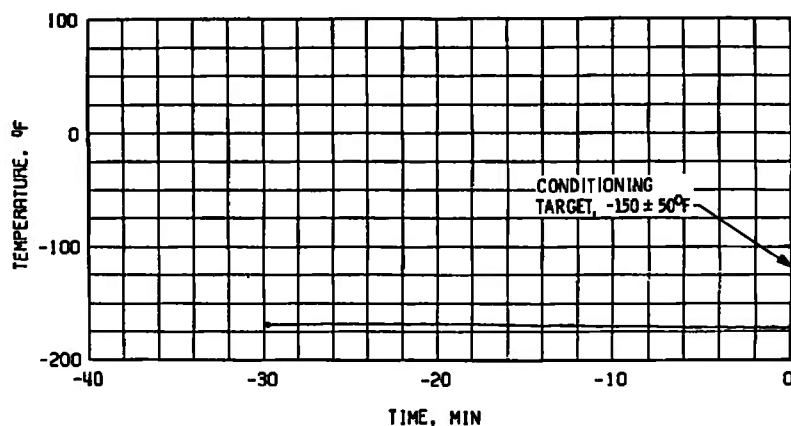
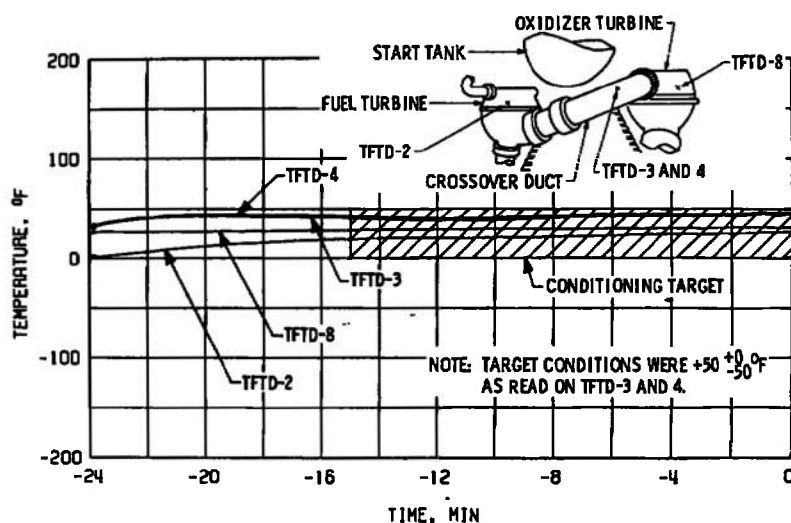


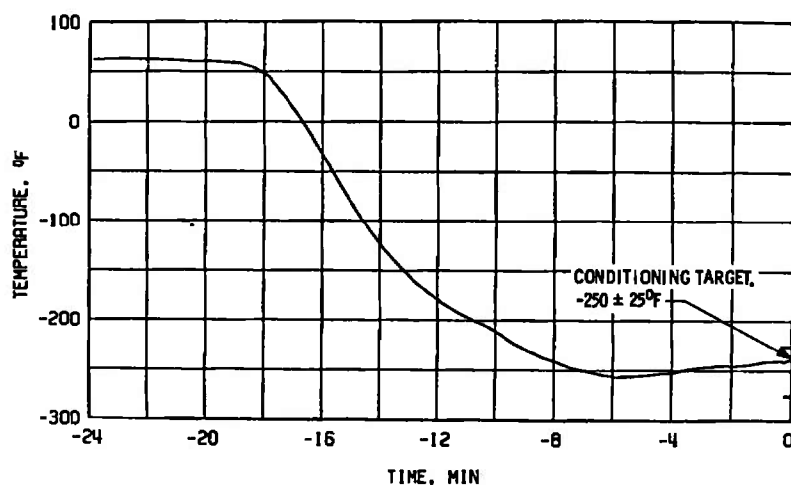
Fig. 16 Engine Ambient and Combustion Chamber Pressure, Firing 07B



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

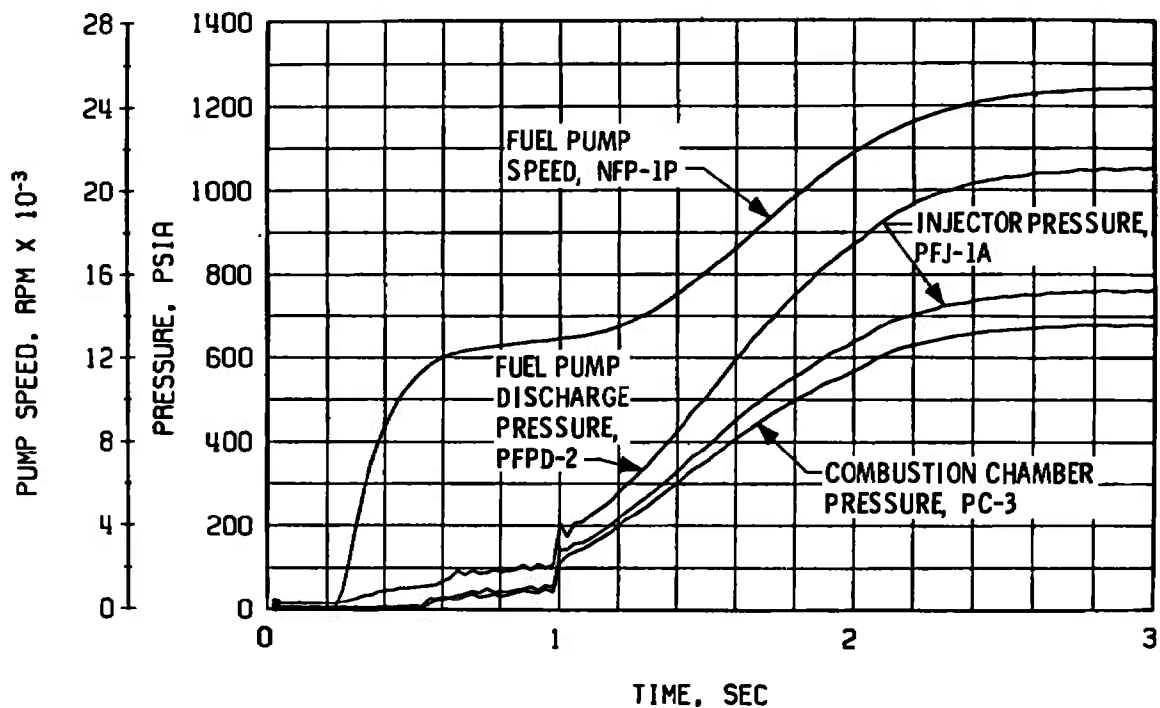


b. Crossover Duct, TFTD

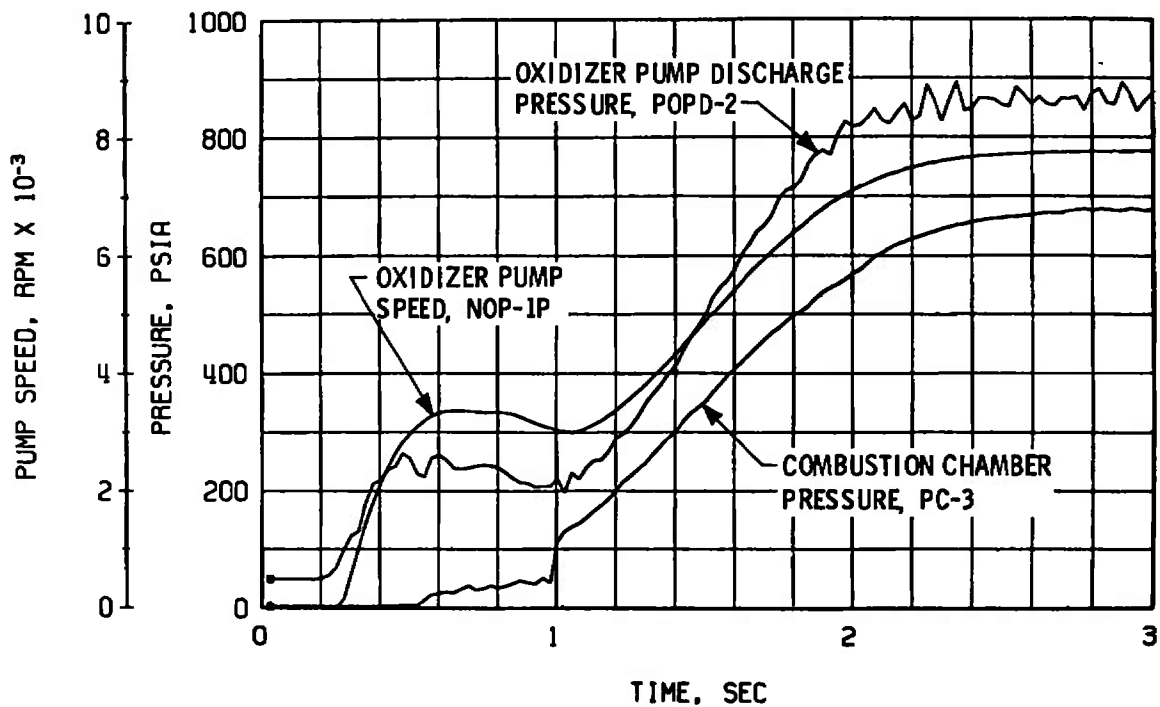


c. Thrust Chamber Throat, TTC-1P

Fig. 17 Thermal Conditioning History of Engine Components, Firing 07C

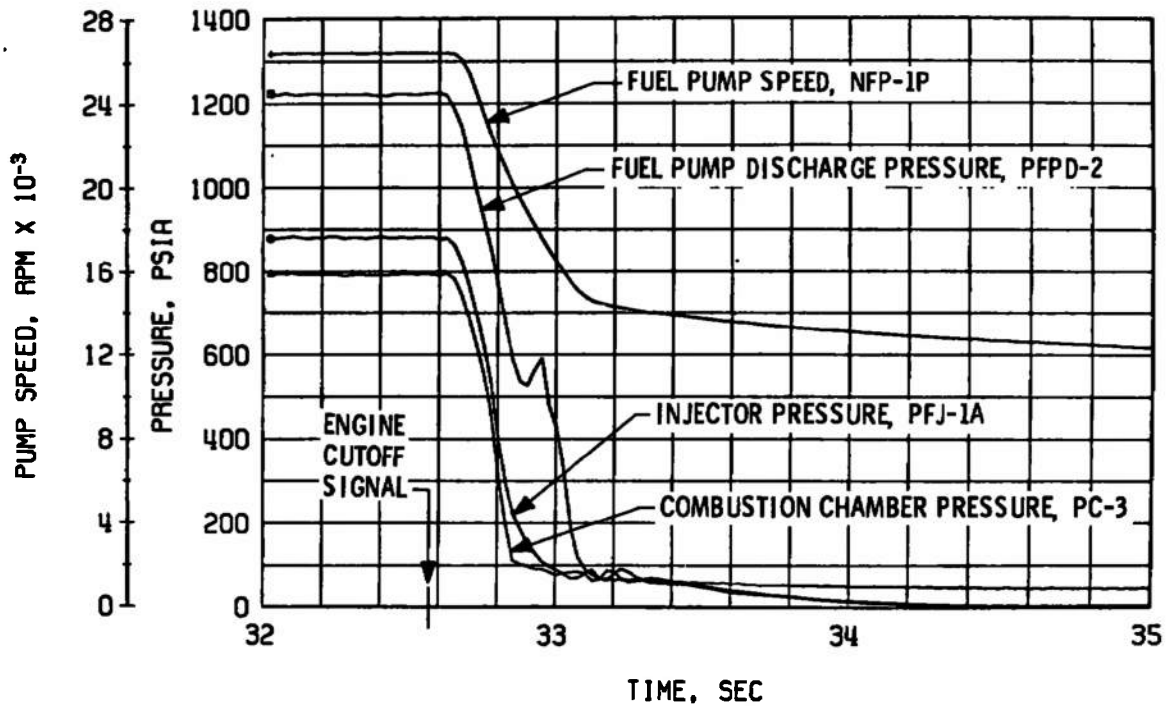


a. Thrust Chamber Fuel System, Start

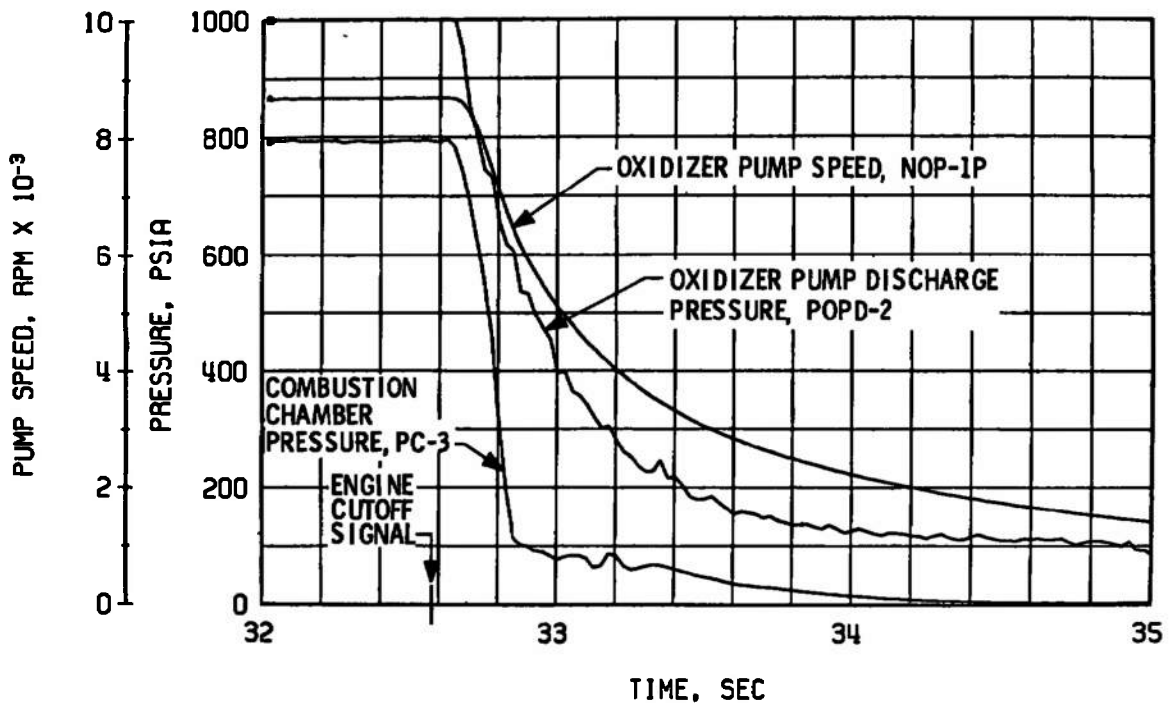


b. Thrust Chamber Oxidizer System, Start

Fig. 18 Engine Transient Operation, Firing 07C

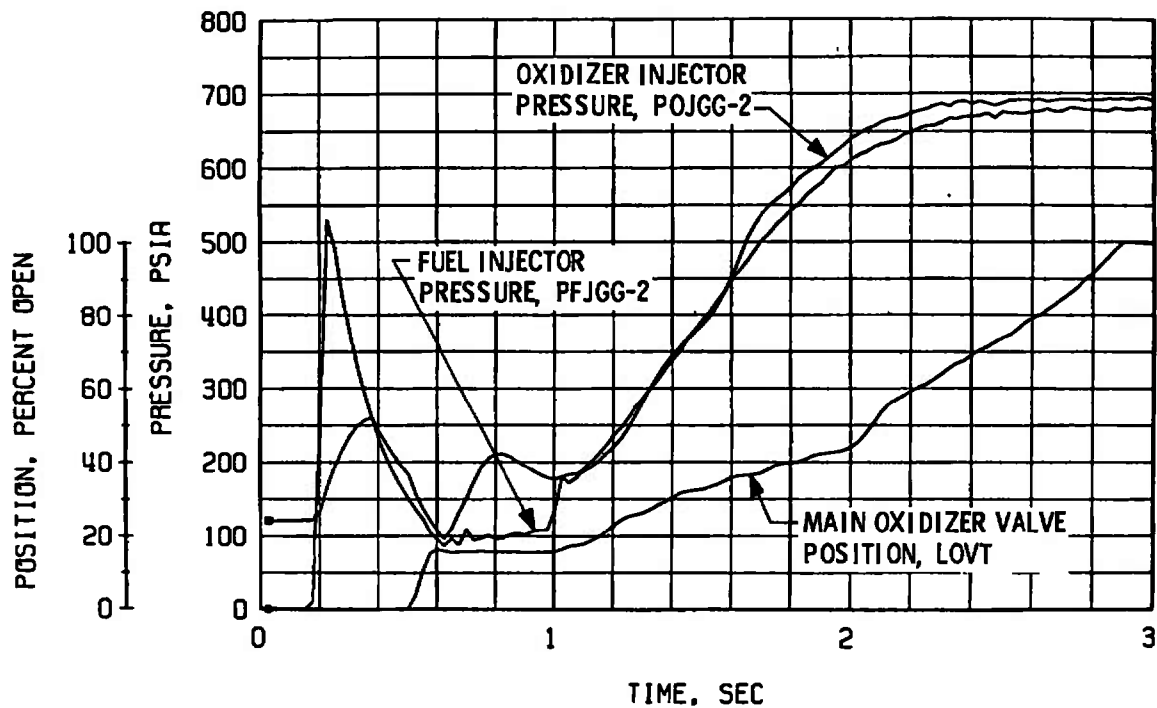


c. Thrust Chamber Fuel System, Start

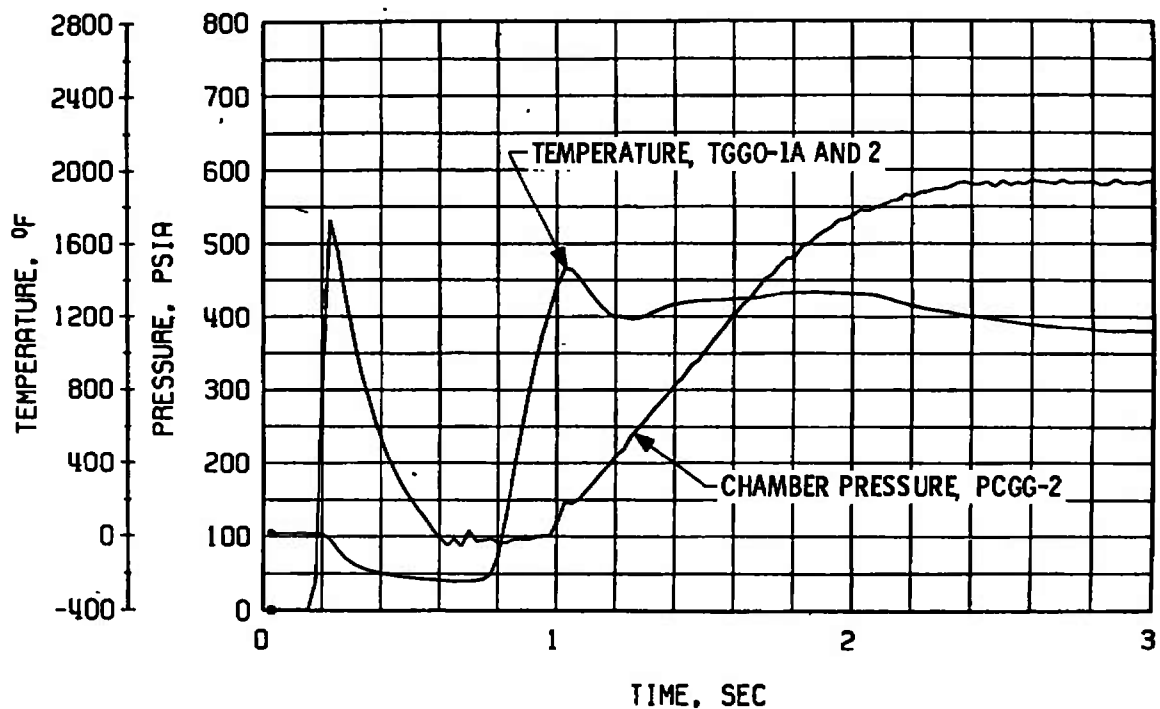


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 18 Continued



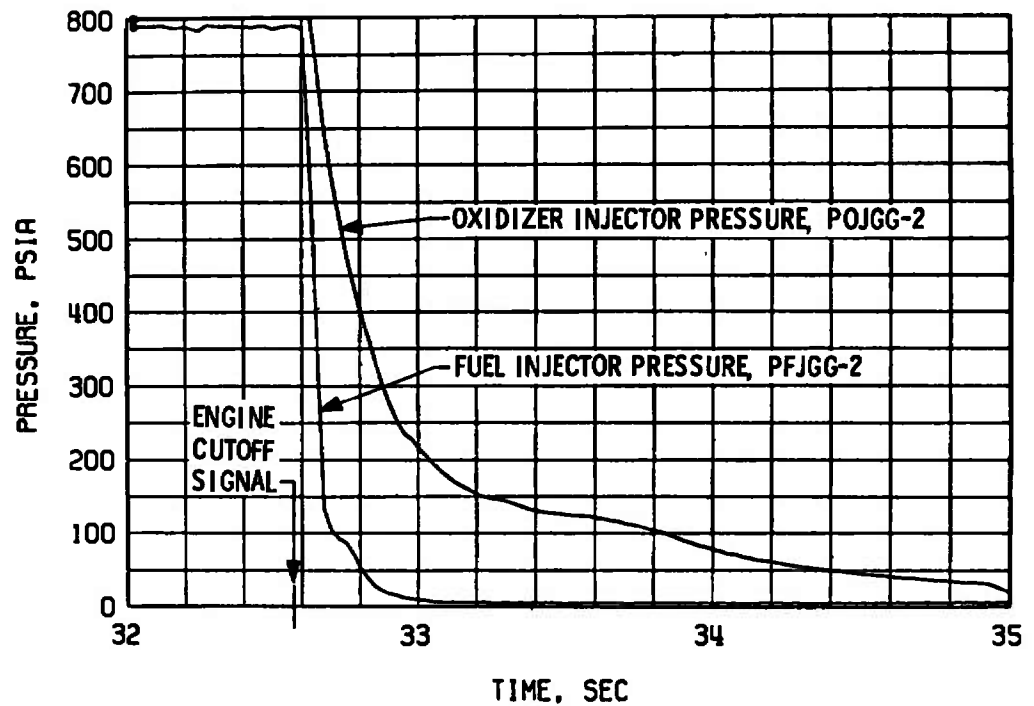
e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start



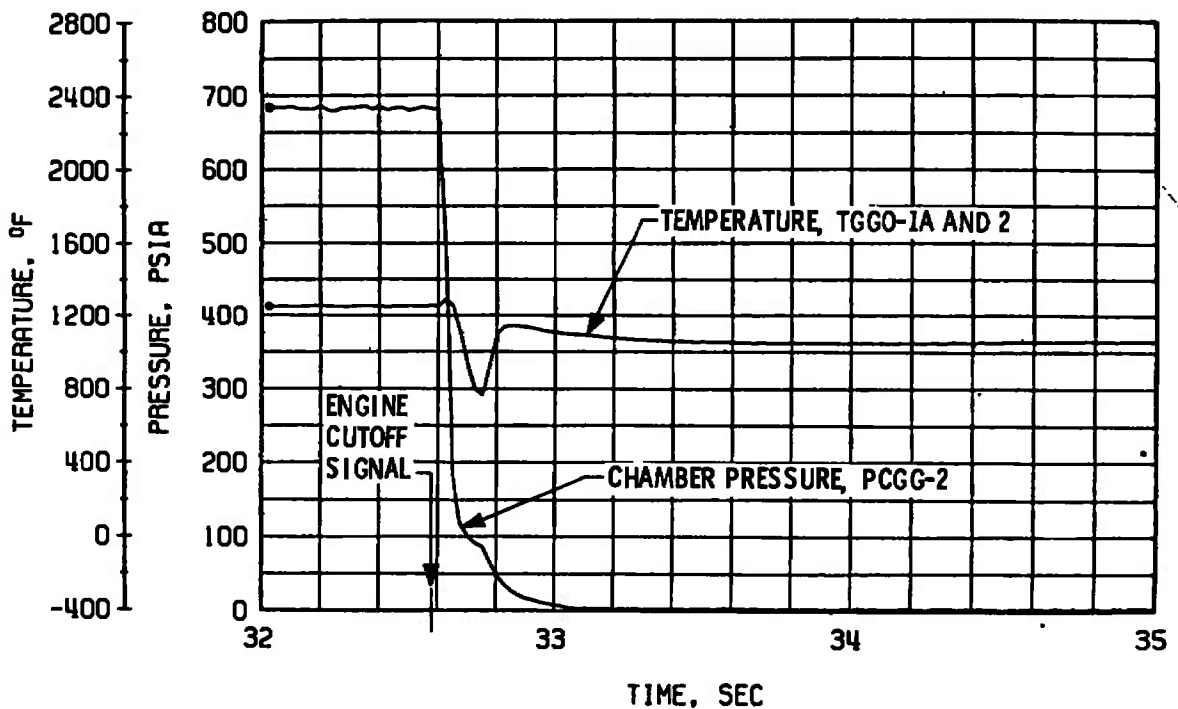
f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 18 Continued





g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 18 Concluded

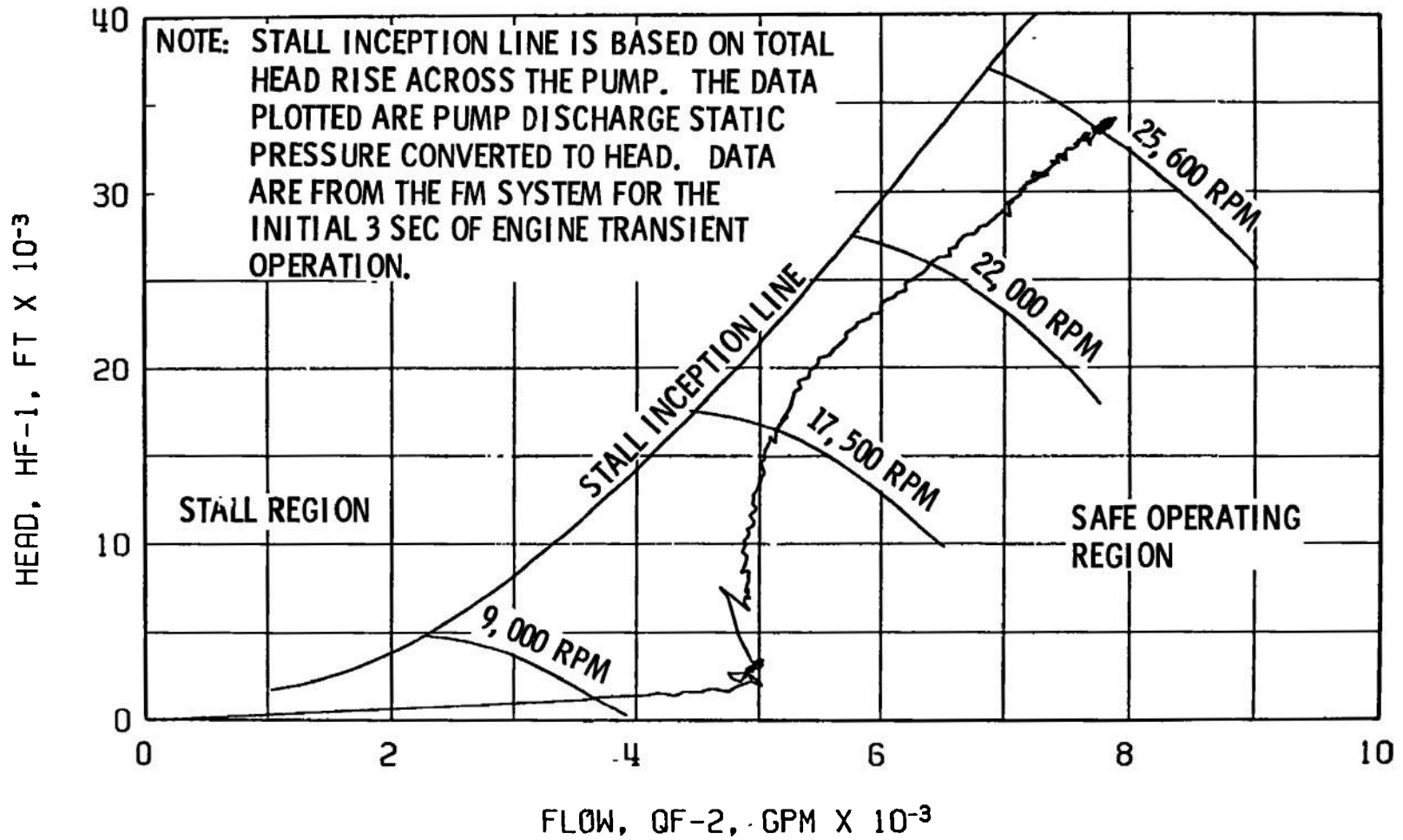


Fig. 19 Fuel Pump Start Transient Performance, Firing 07C

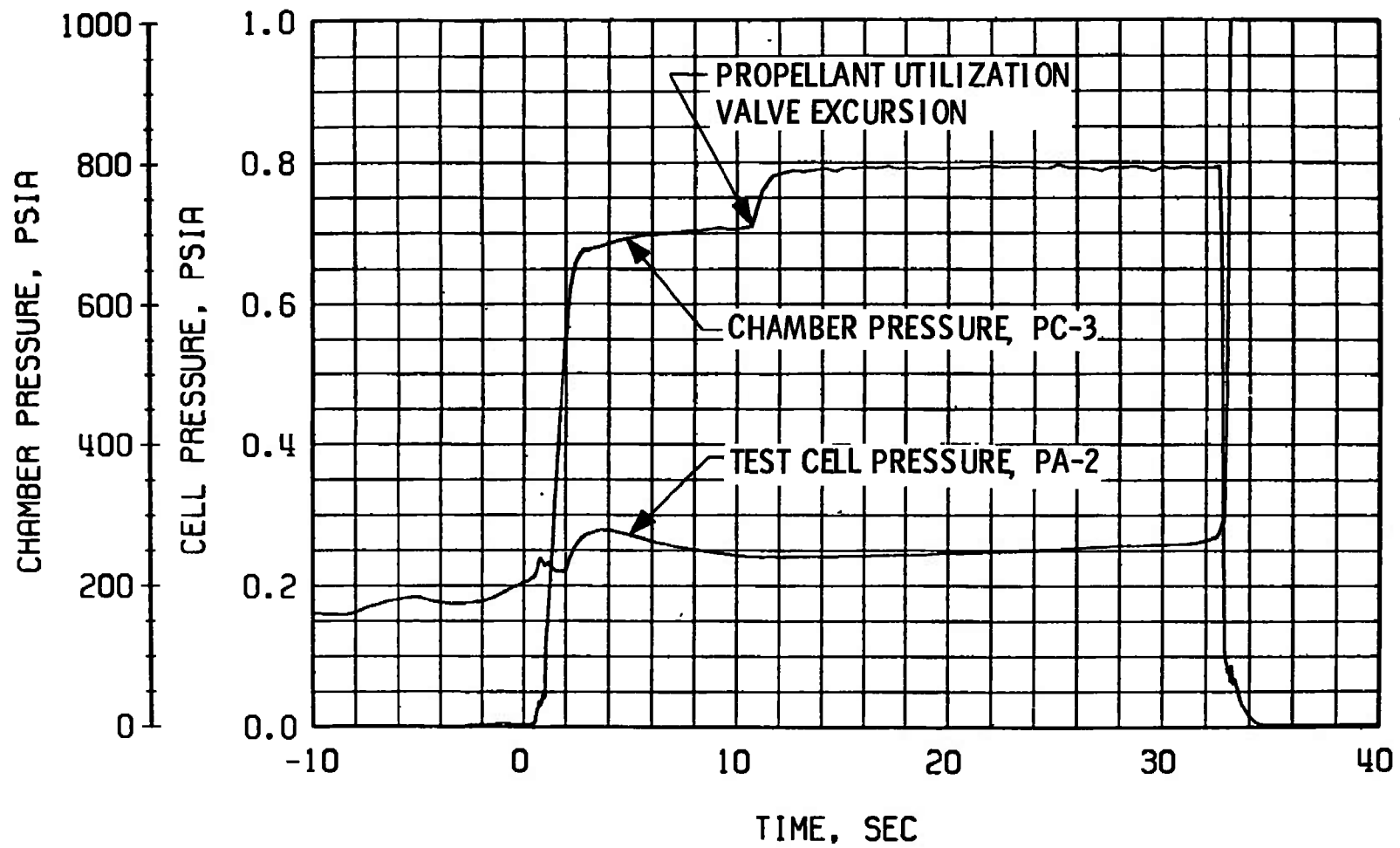
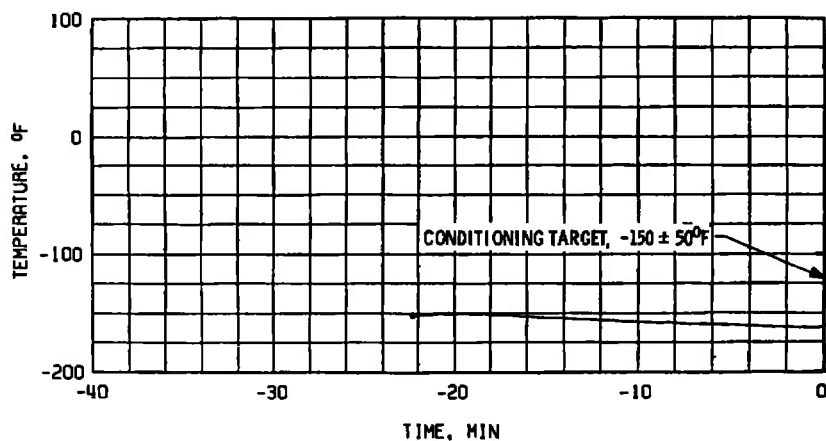
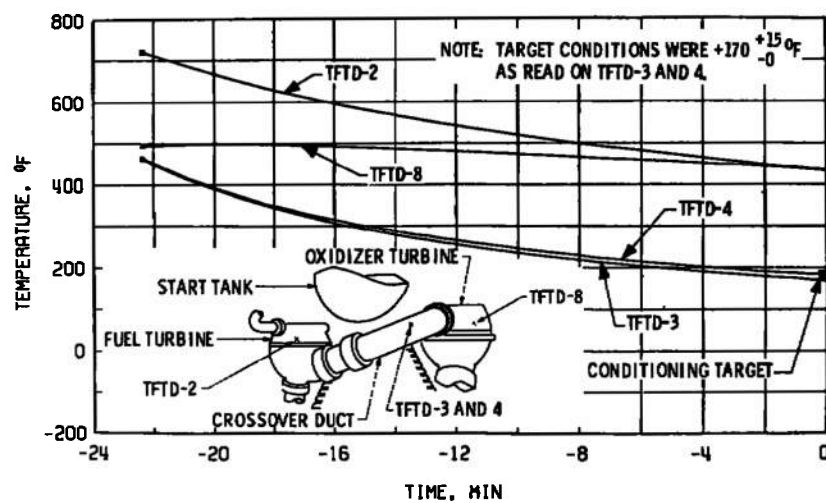


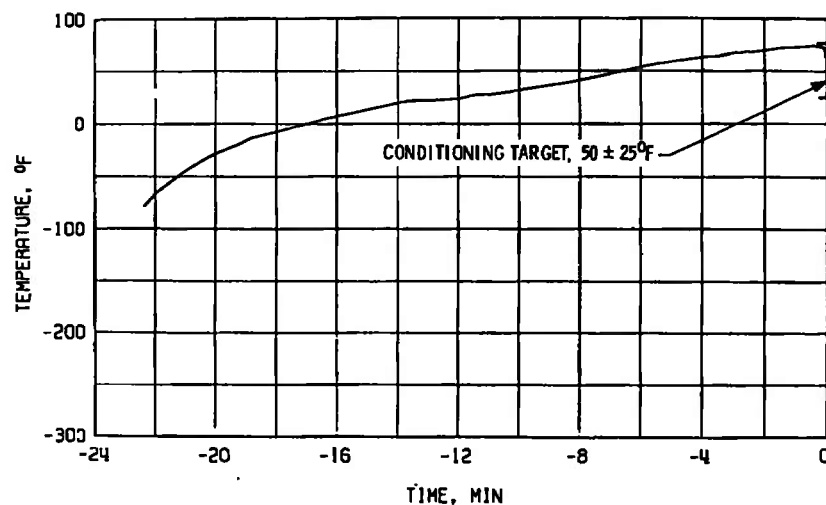
Fig. 20 Engine Ambient and Combustion Chamber Pressure, Firing 07C



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

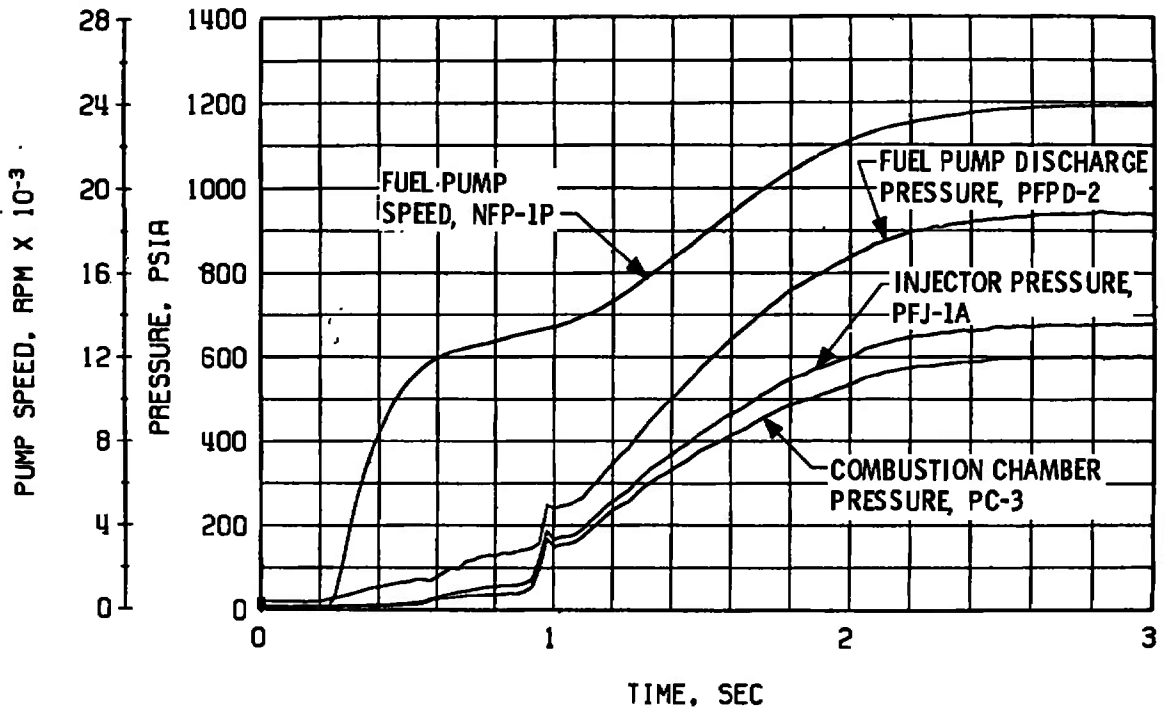


b. Crossover Duct, TTFD

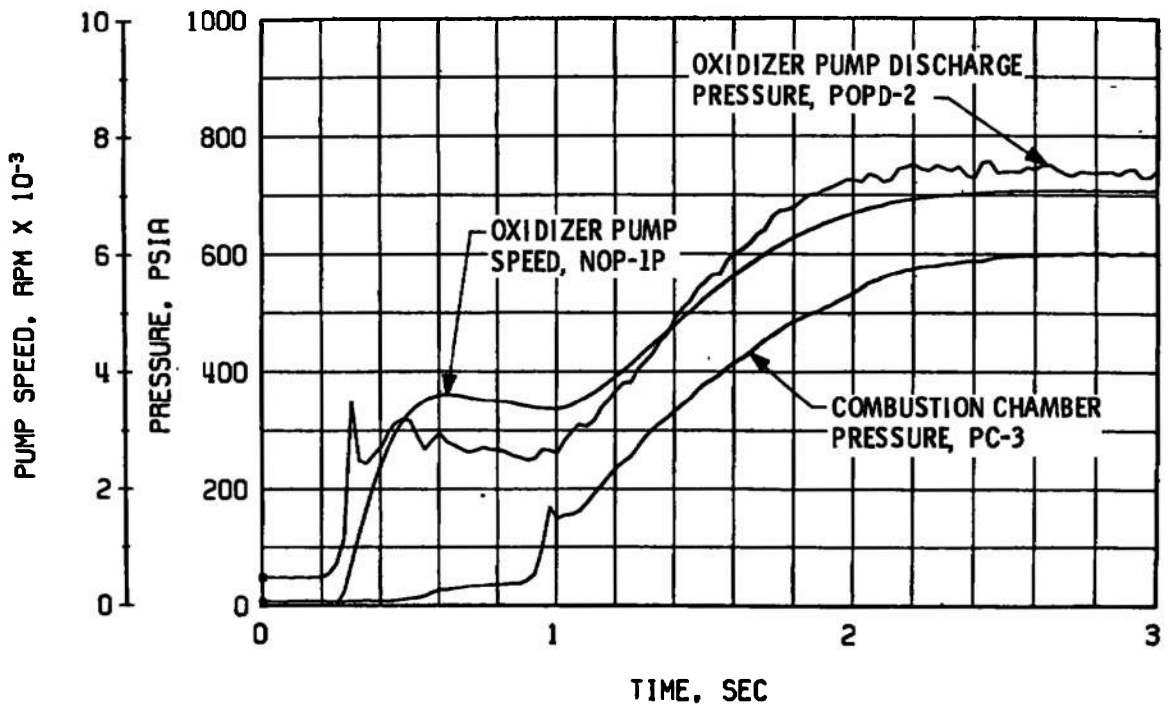


c. Thrust Chamber Throat, TTC-1P

Fig. 21 Thermal Conditioning History of Engine Components, Firing 07D

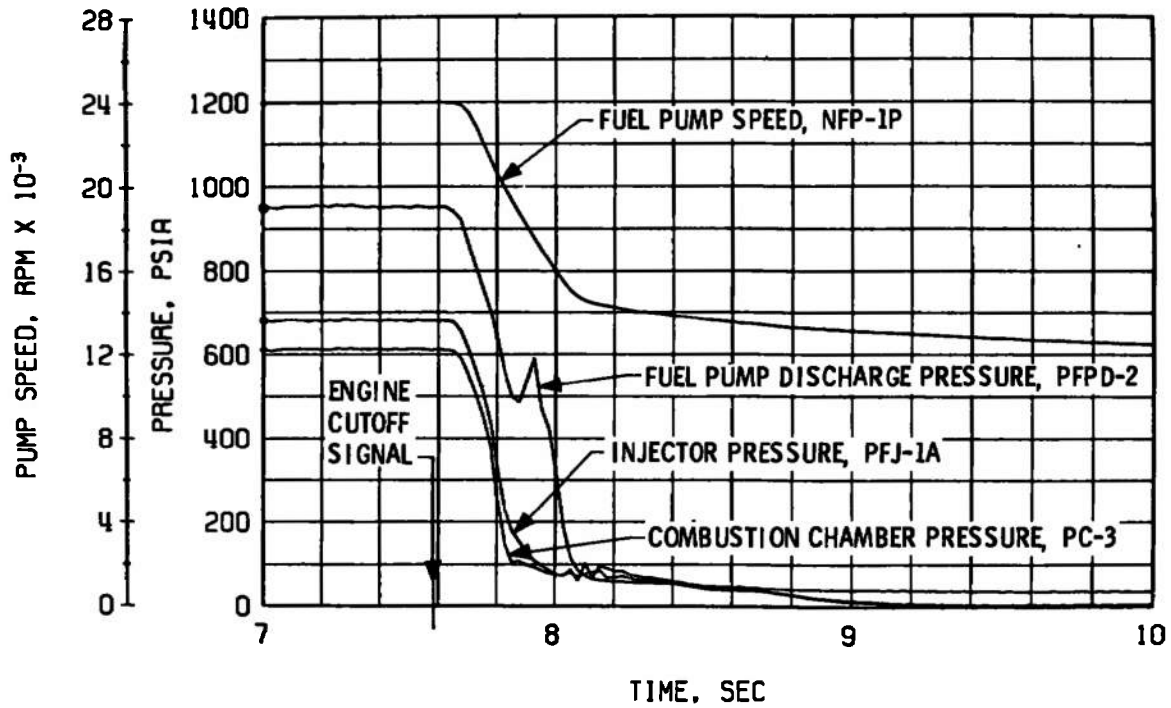


a. Thrust Chamber Fuel System, Start

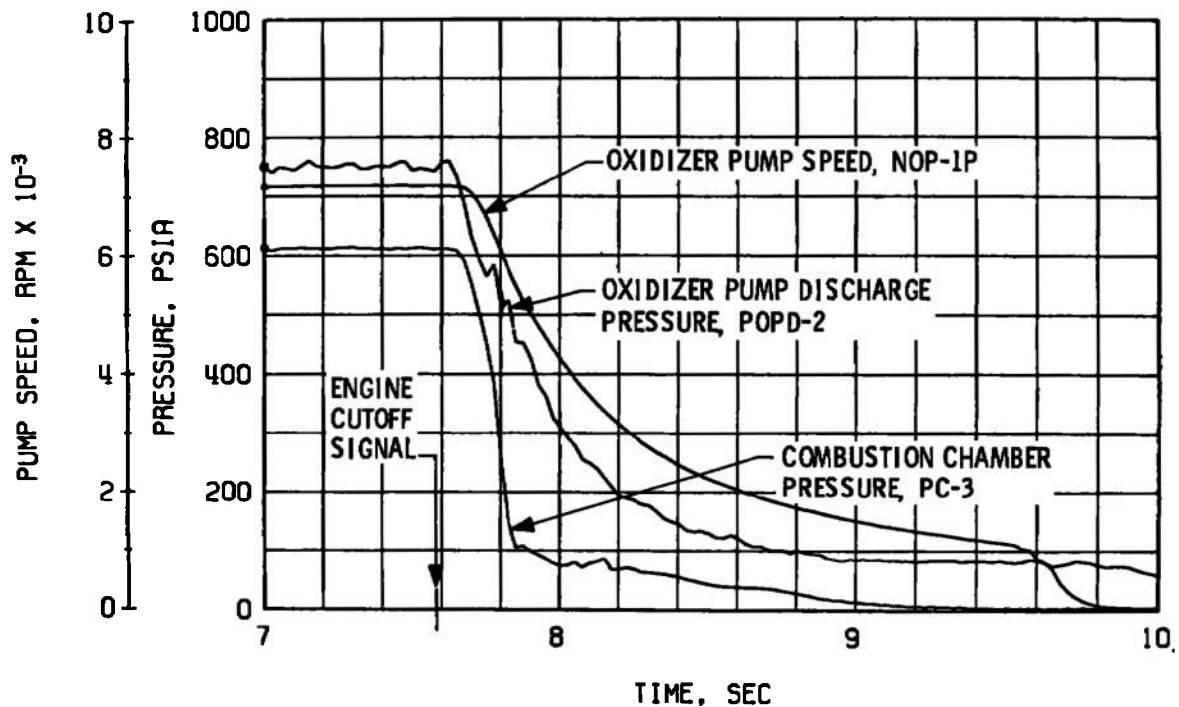


b. Thrust Chamber Oxidizer System, Start

Fig. 22 Engine Transient Operation, Firing 07D

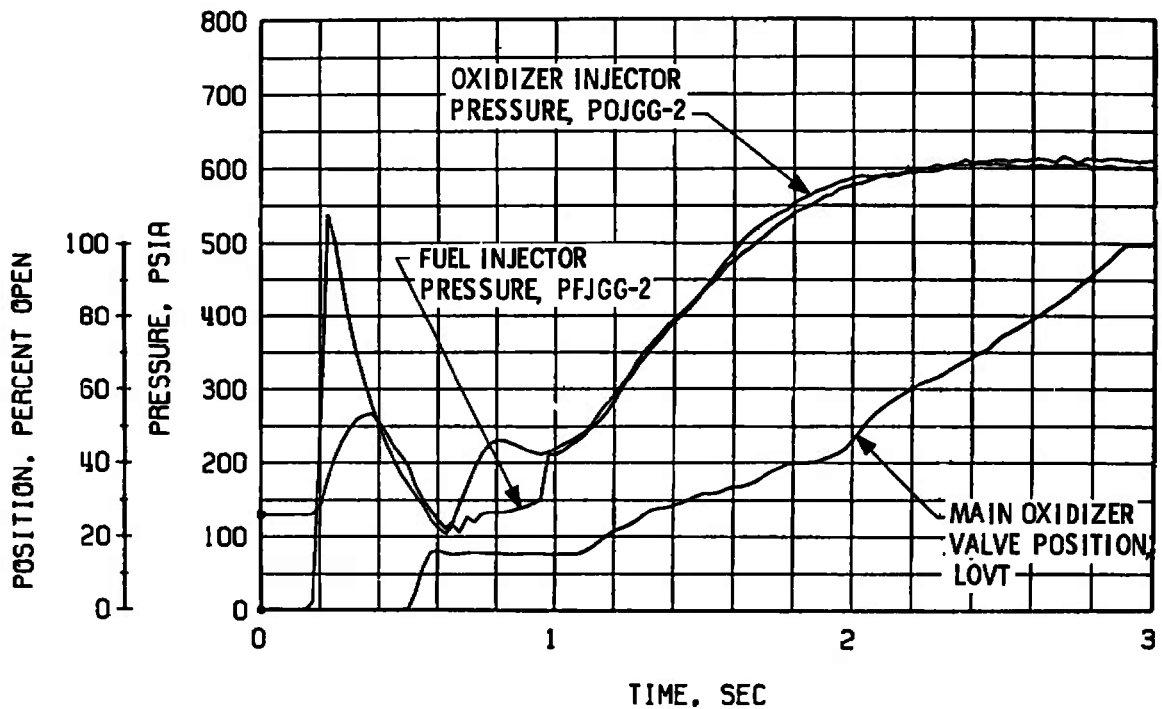


c. Thrust Chamber Fuel System, Shutdown

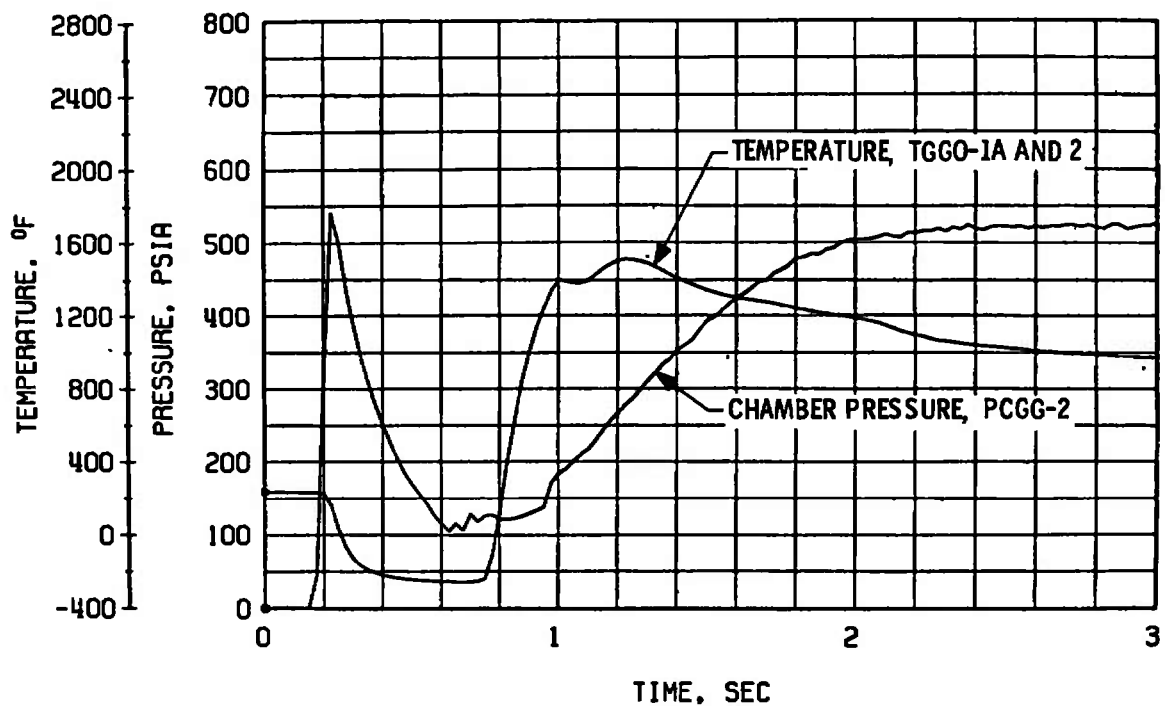


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 22 Continued

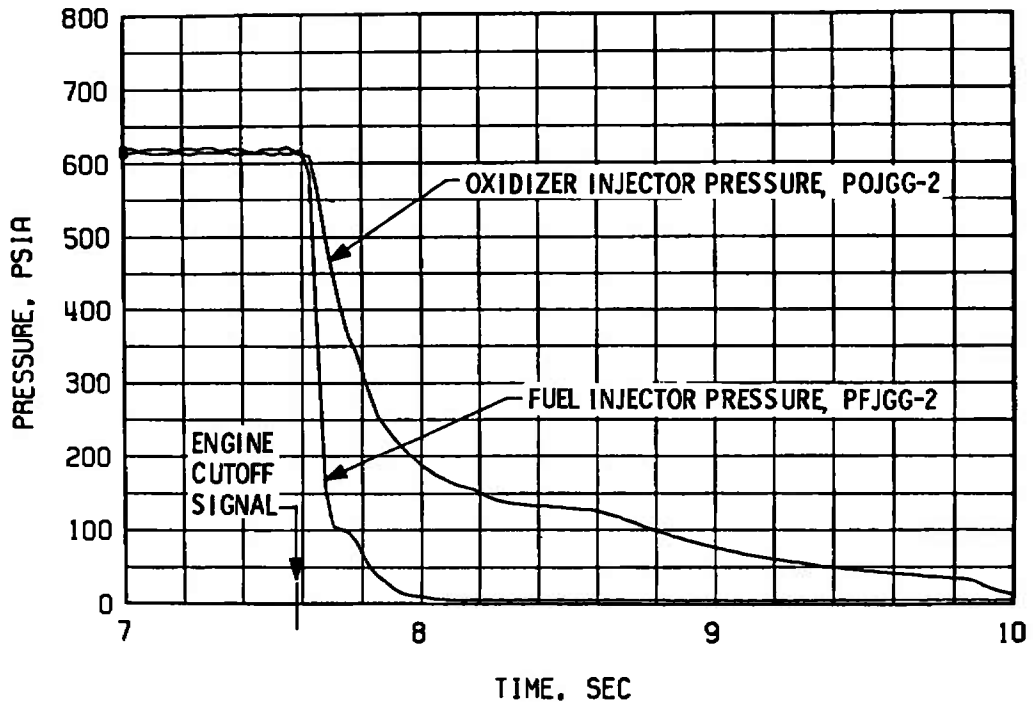


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

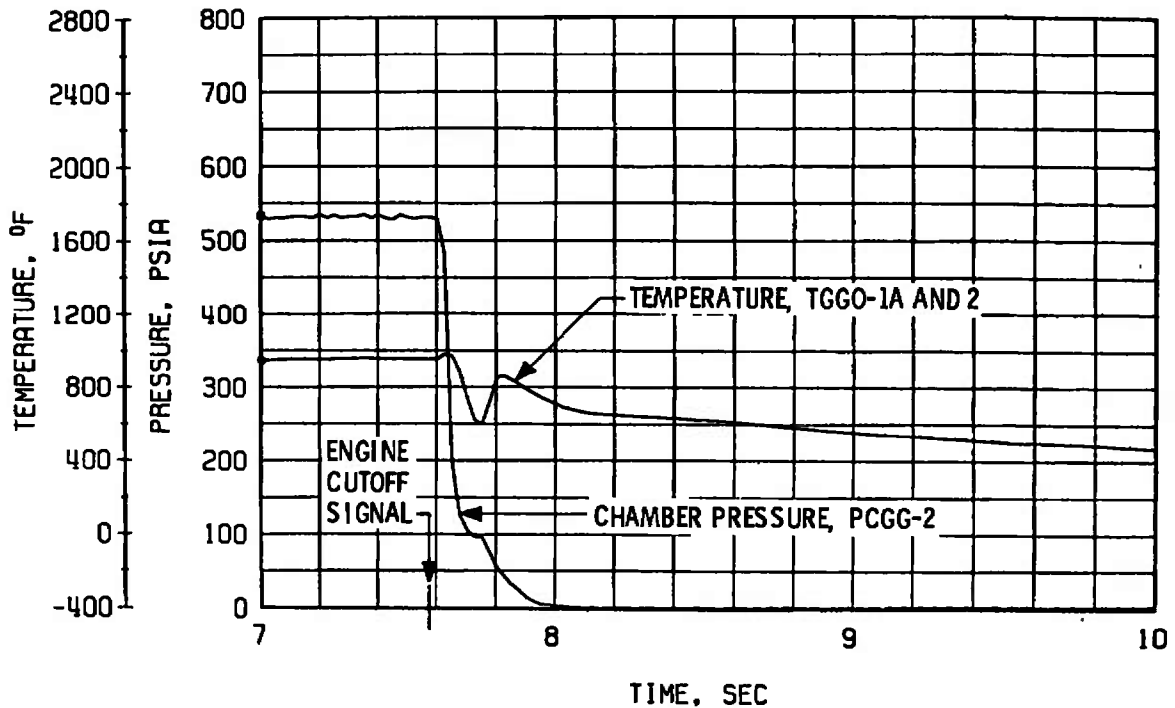


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 22 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 22 Concluded



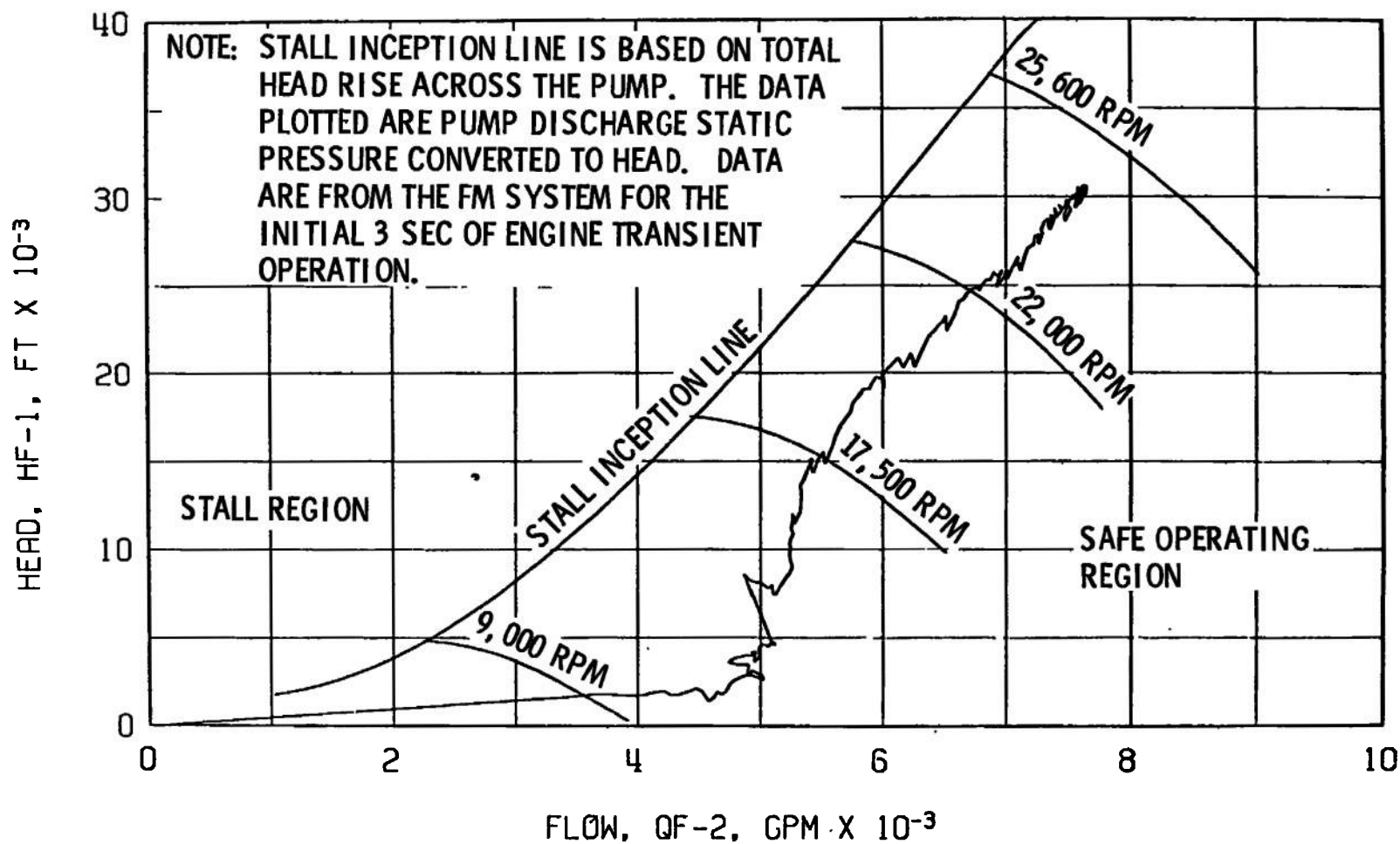


Fig. 23 Fuel Pump Start Transient Performance, Firing 07D

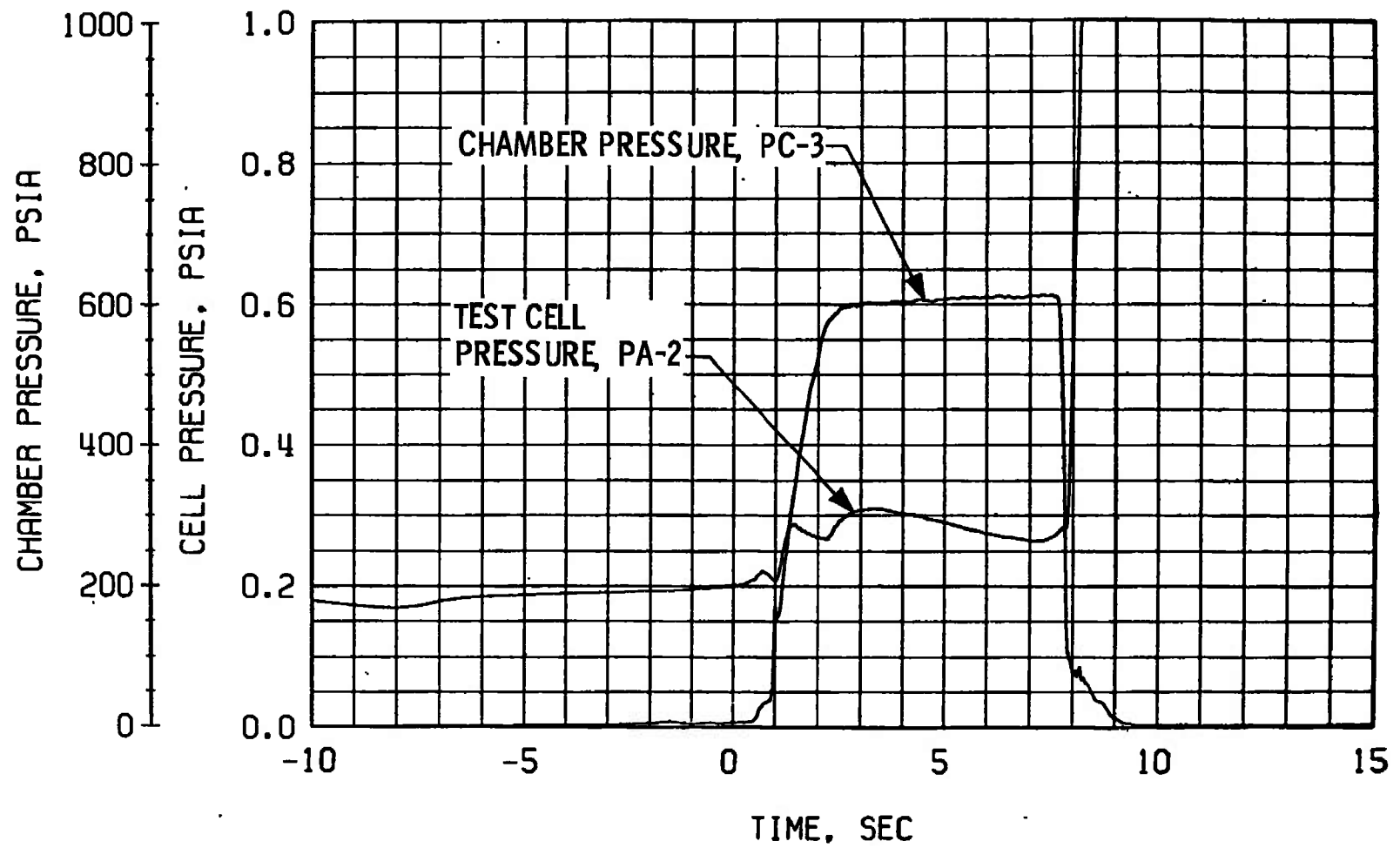
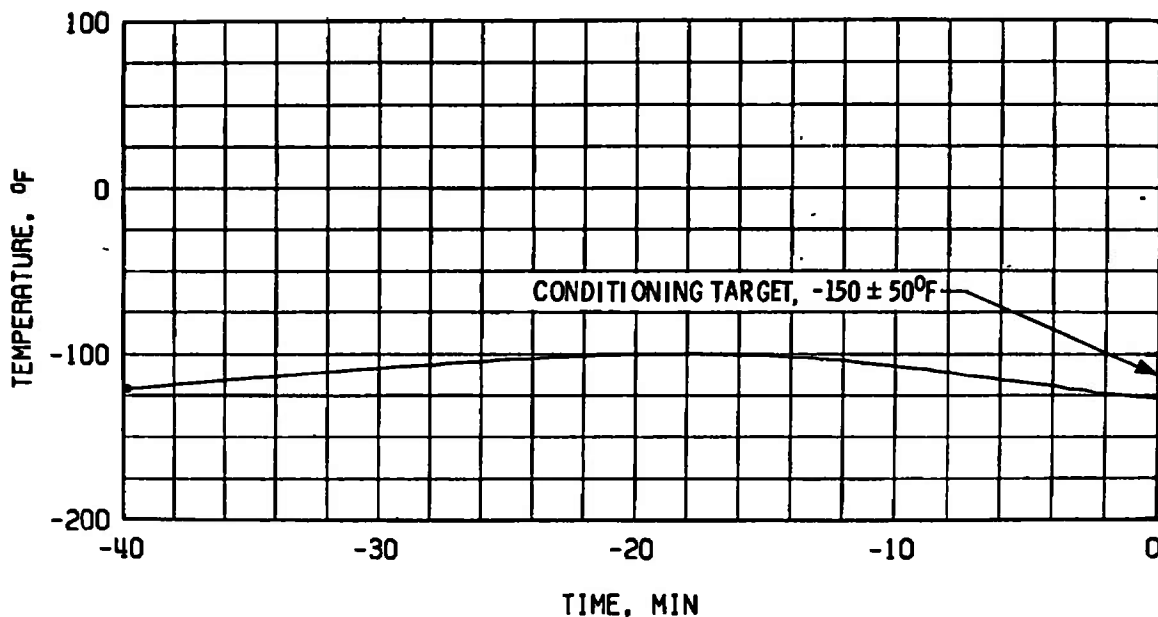
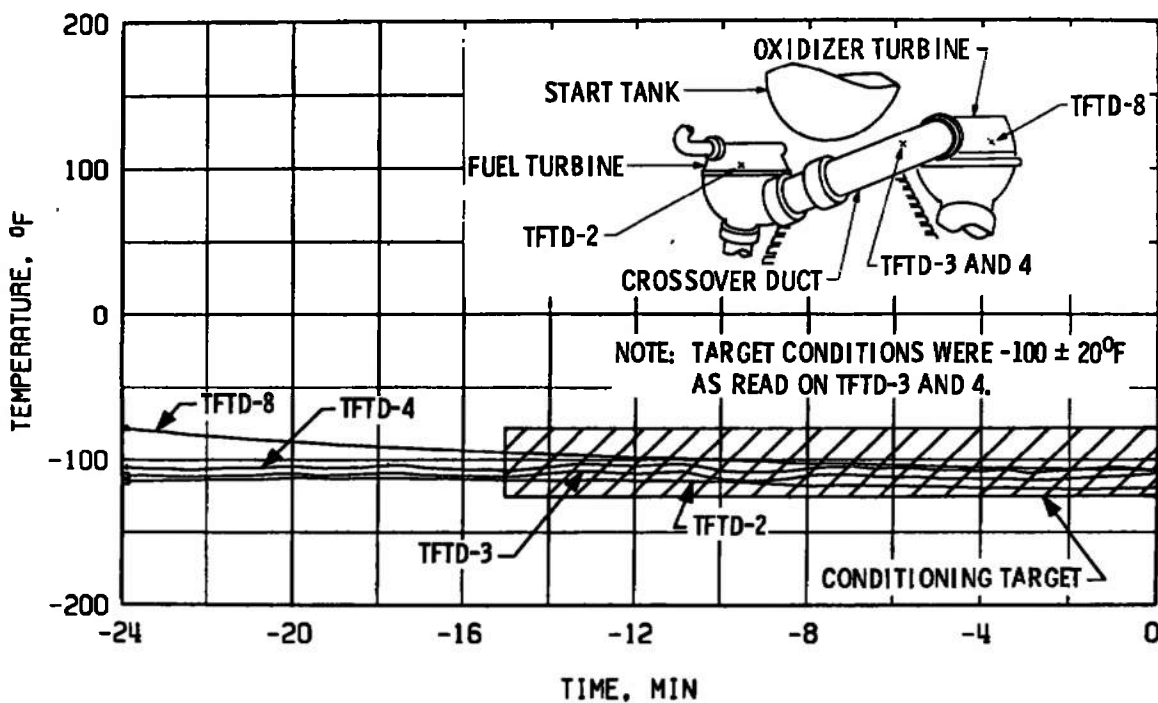


Fig. 24 Engine Ambient and Combustion Chamber Pressure, Firing 07D

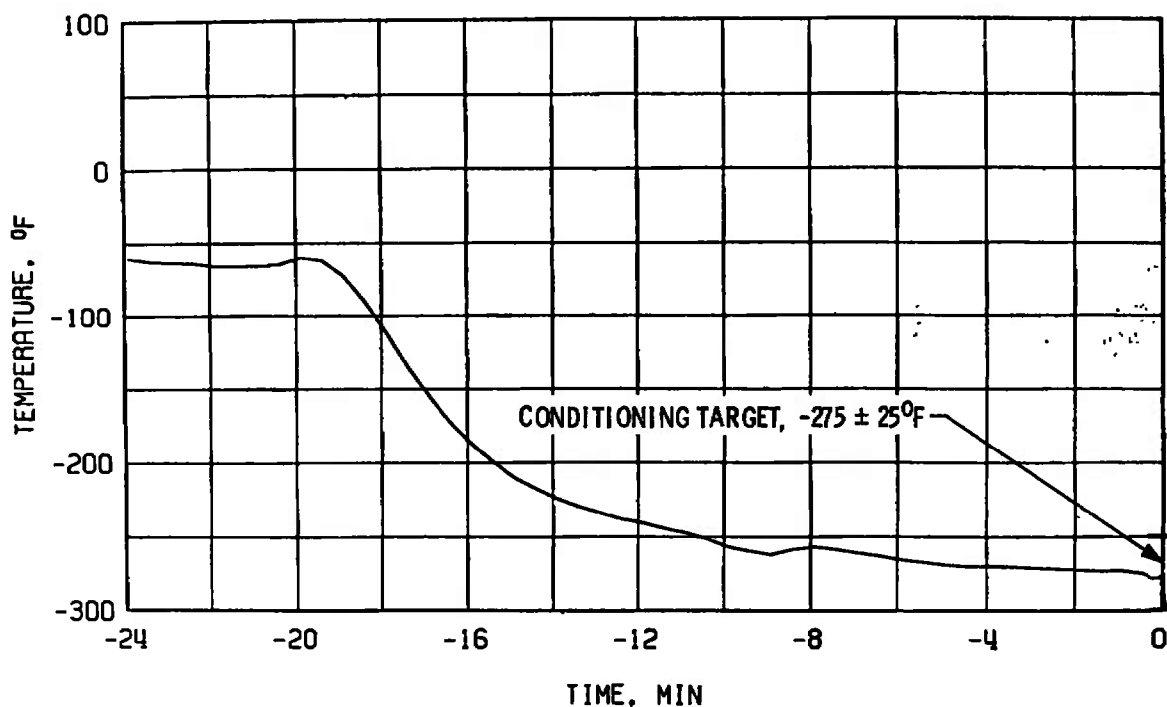


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

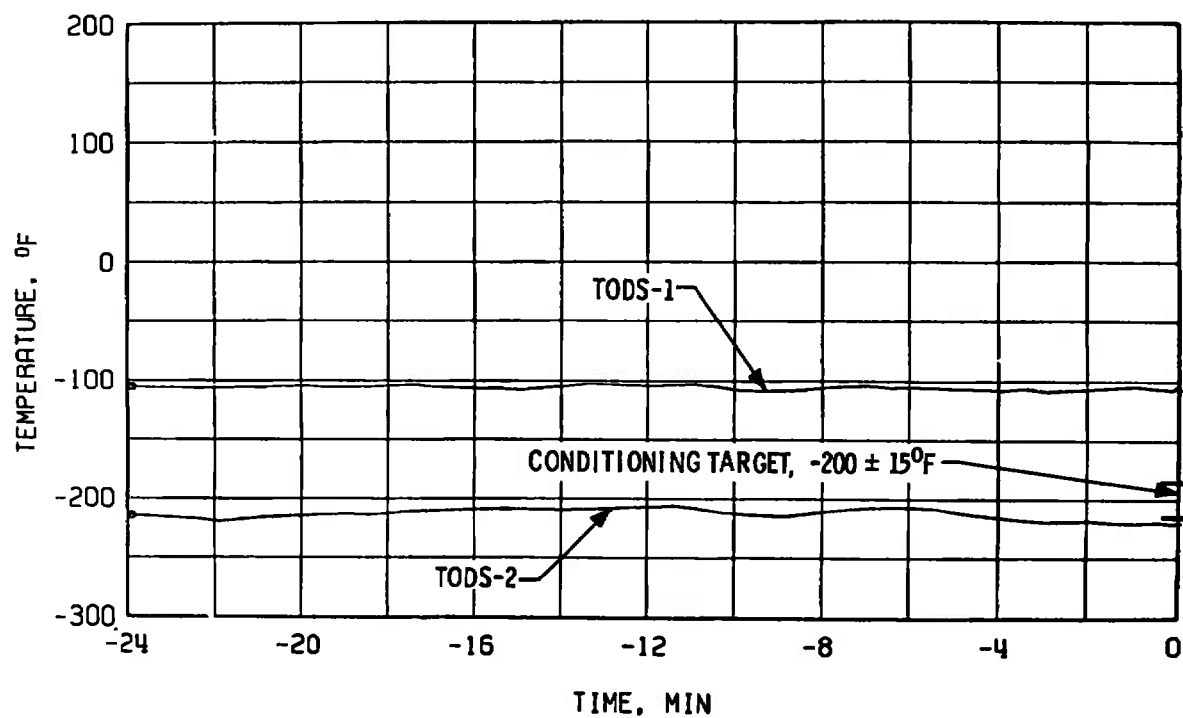


b. Crossover Duct, TFTD

Fig. 25 Thermal Conditioning History of Engine Components, Firing 07E

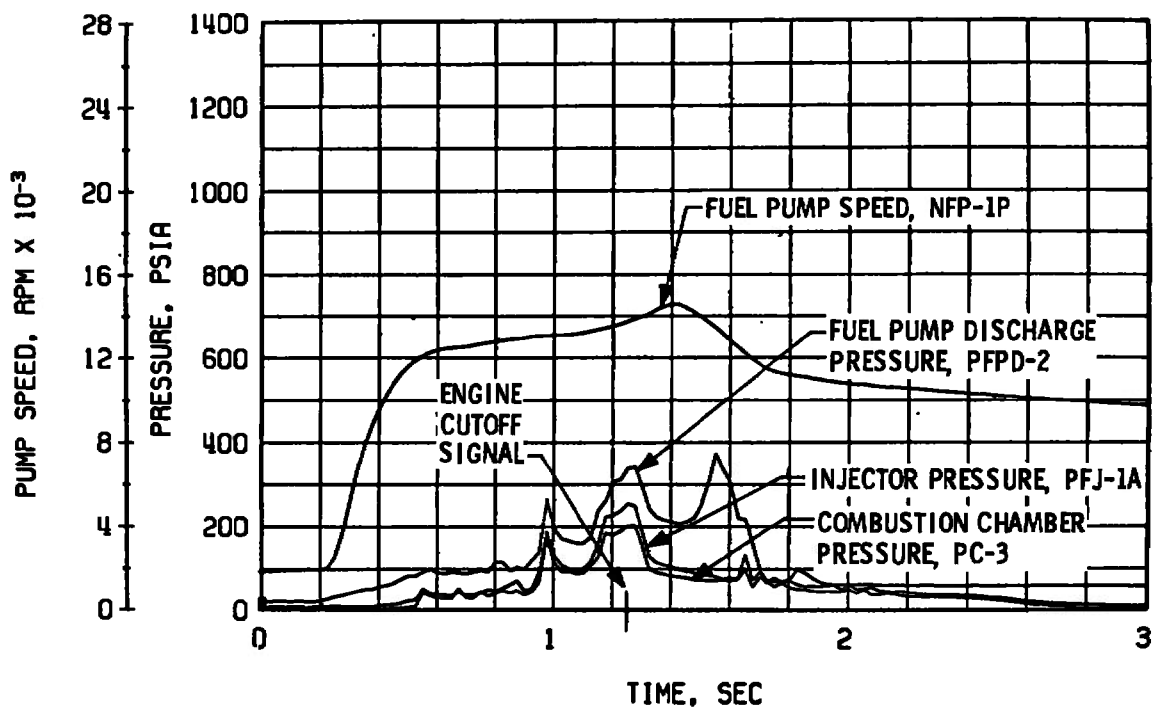


c. Thrust Chamber Throat, TTC-1P

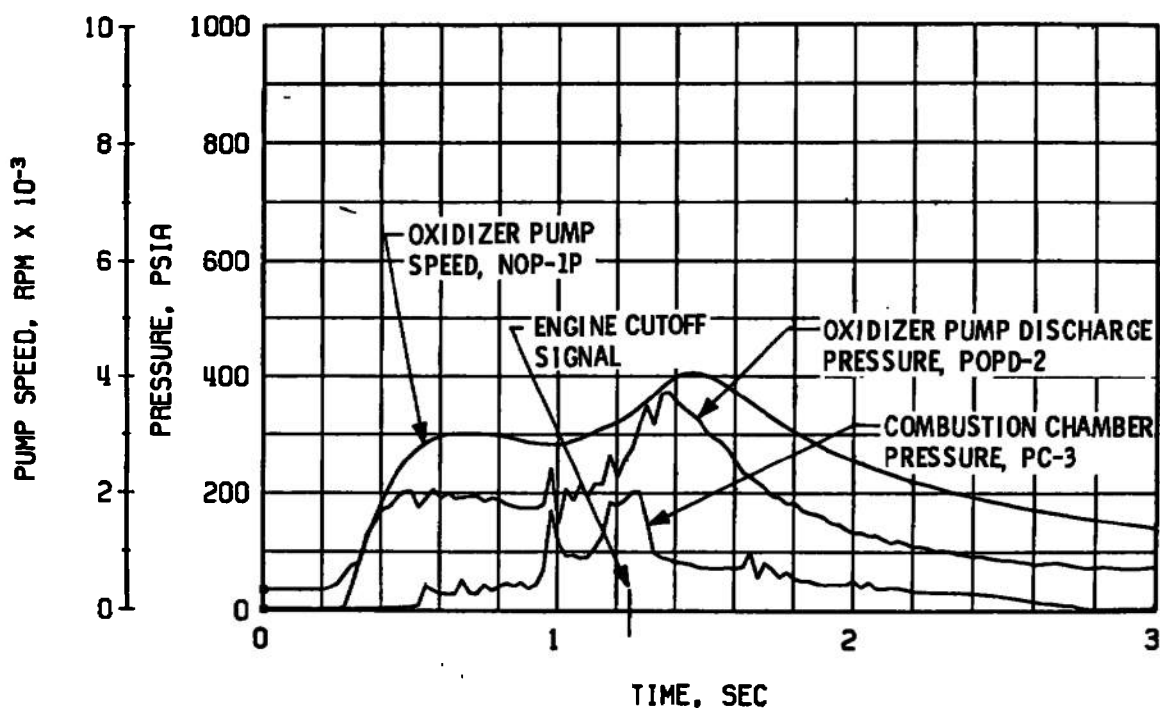


d. Oxidizer Dome, TODS

Fig. 25 Concluded

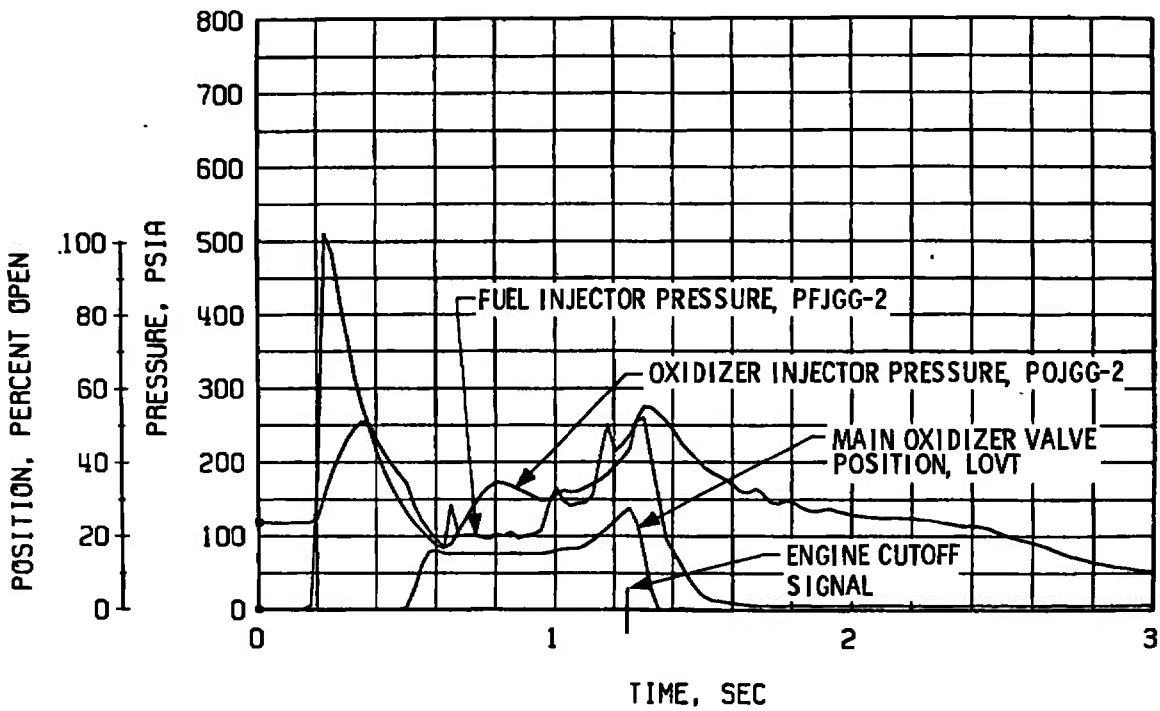


a. Thrust Chamber Fuel System, Start and Shutdown

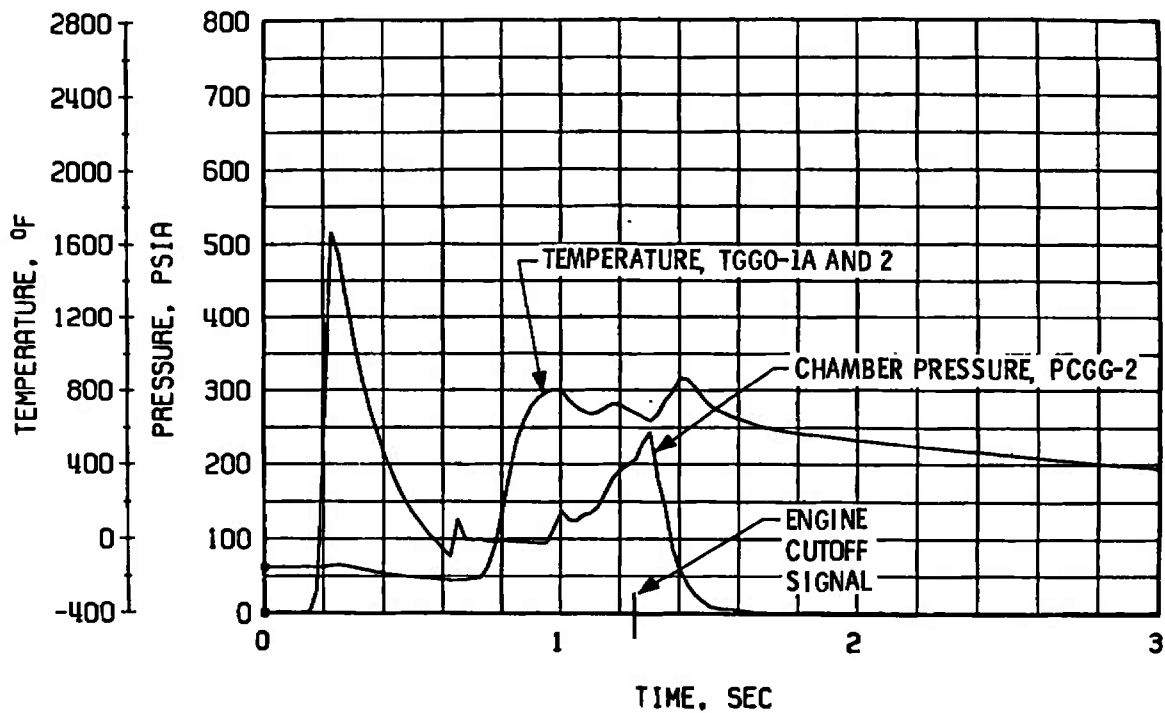


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 26 Engine Transient Operation, Firing 07E



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 26 Concluded

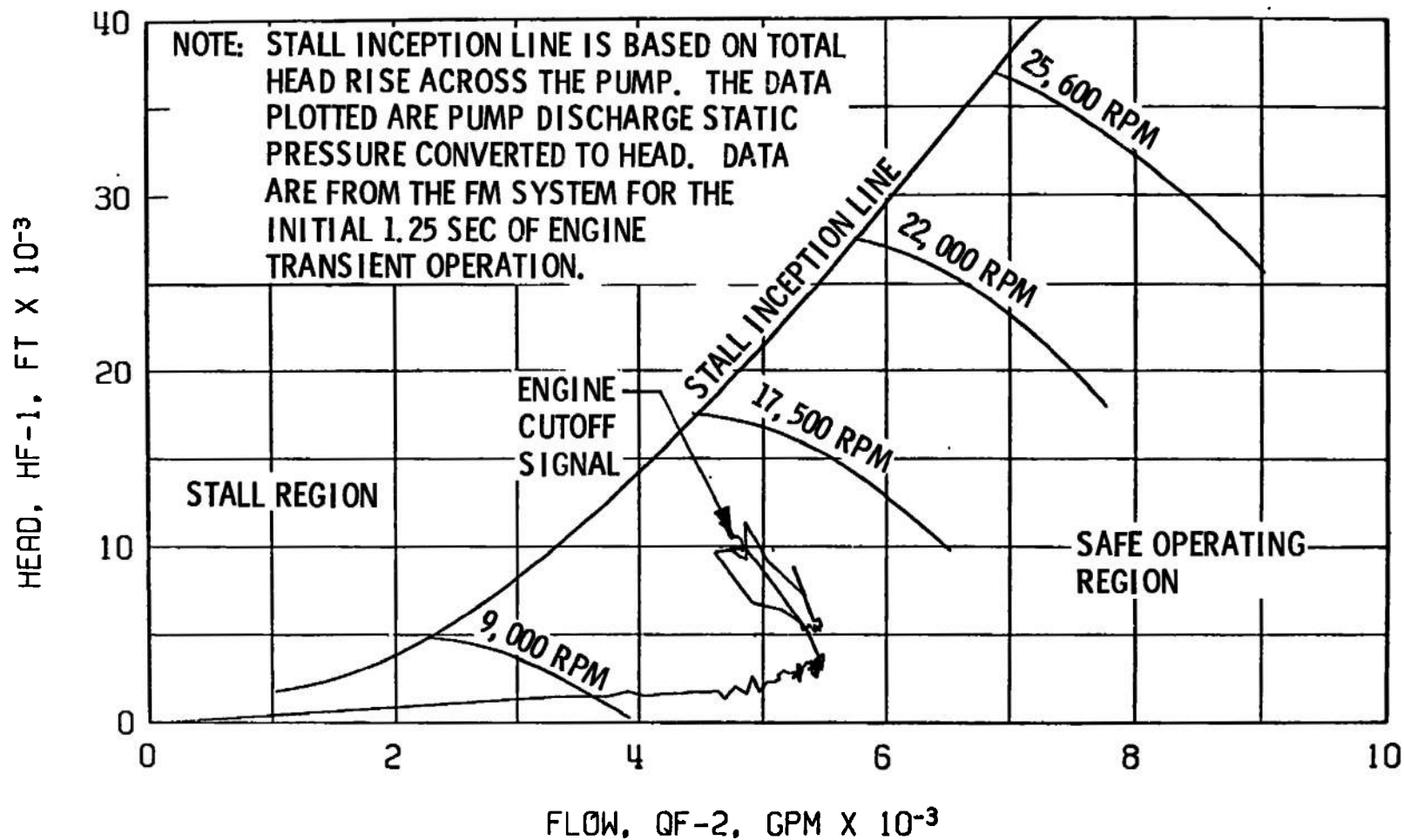


Fig. 27 Fuel Pump Start Transient Performance, Firing 07E

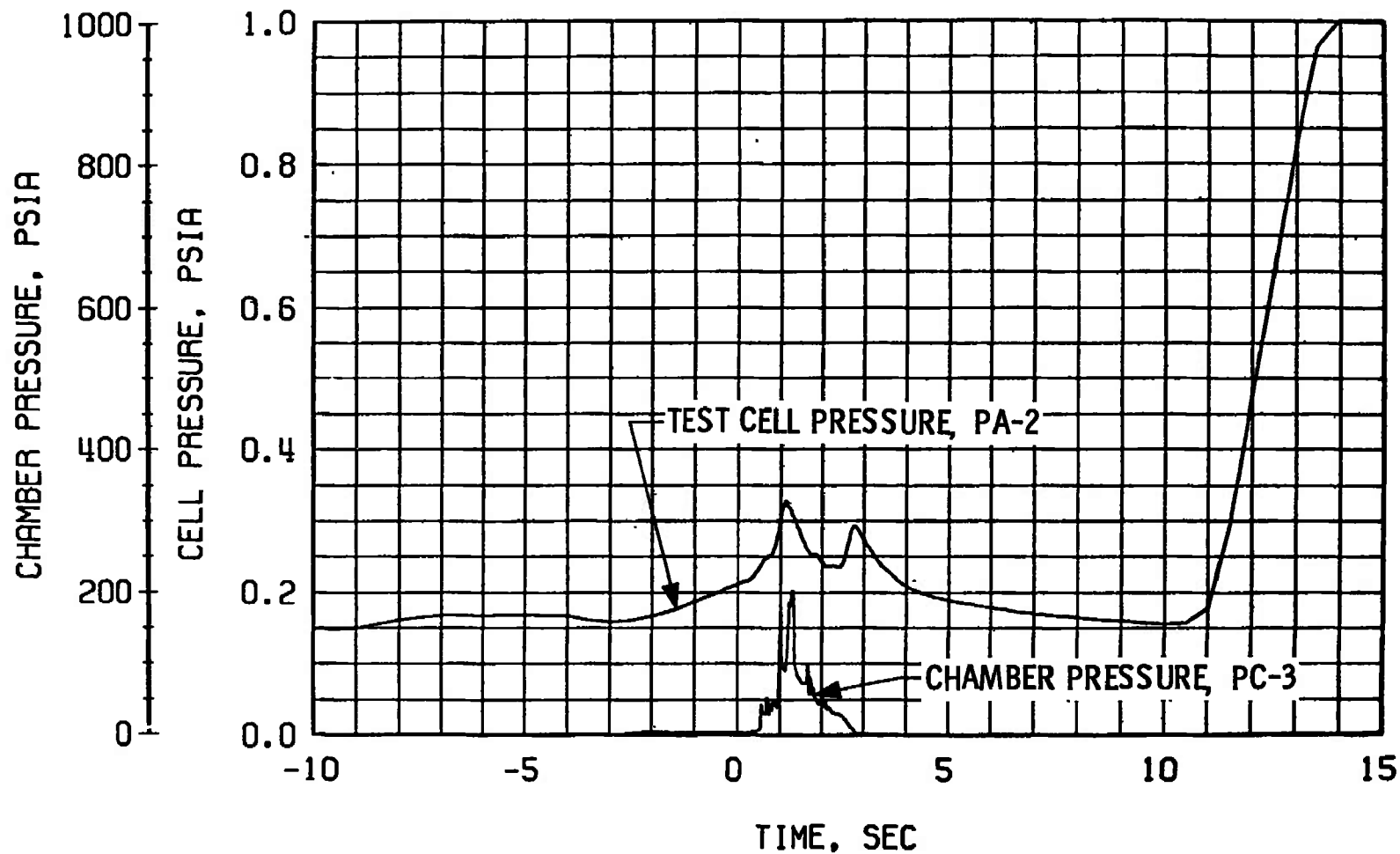
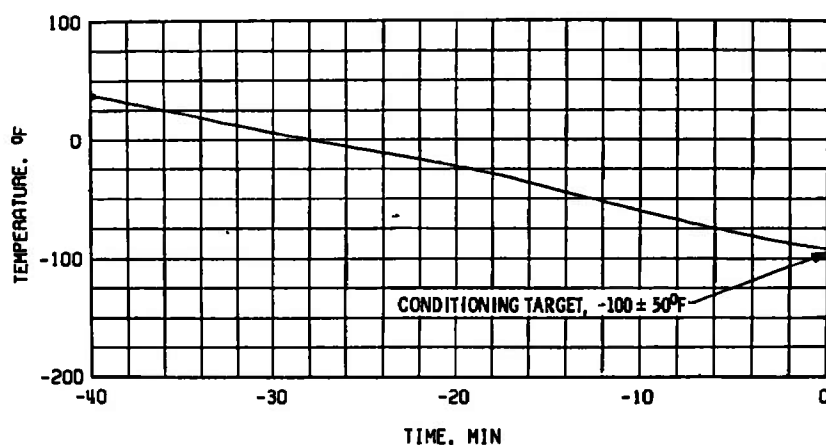
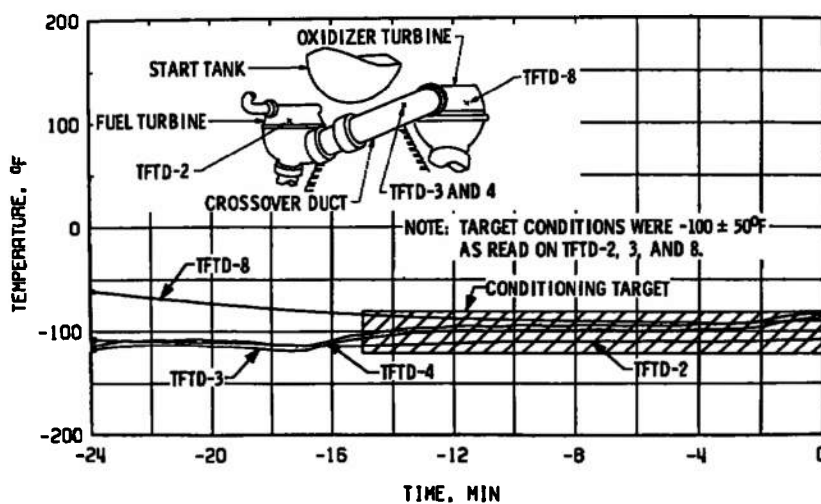


Fig. 28 Engine Ambient and Combustion Chamber Pressure, Firing 07E

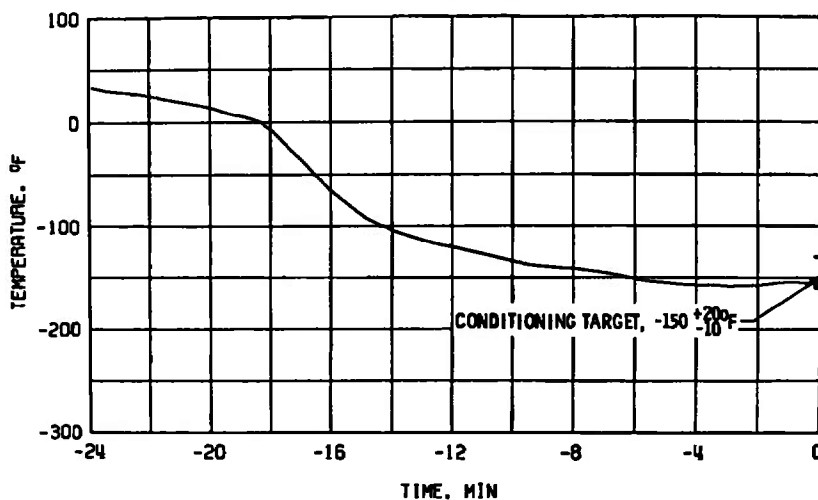




a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

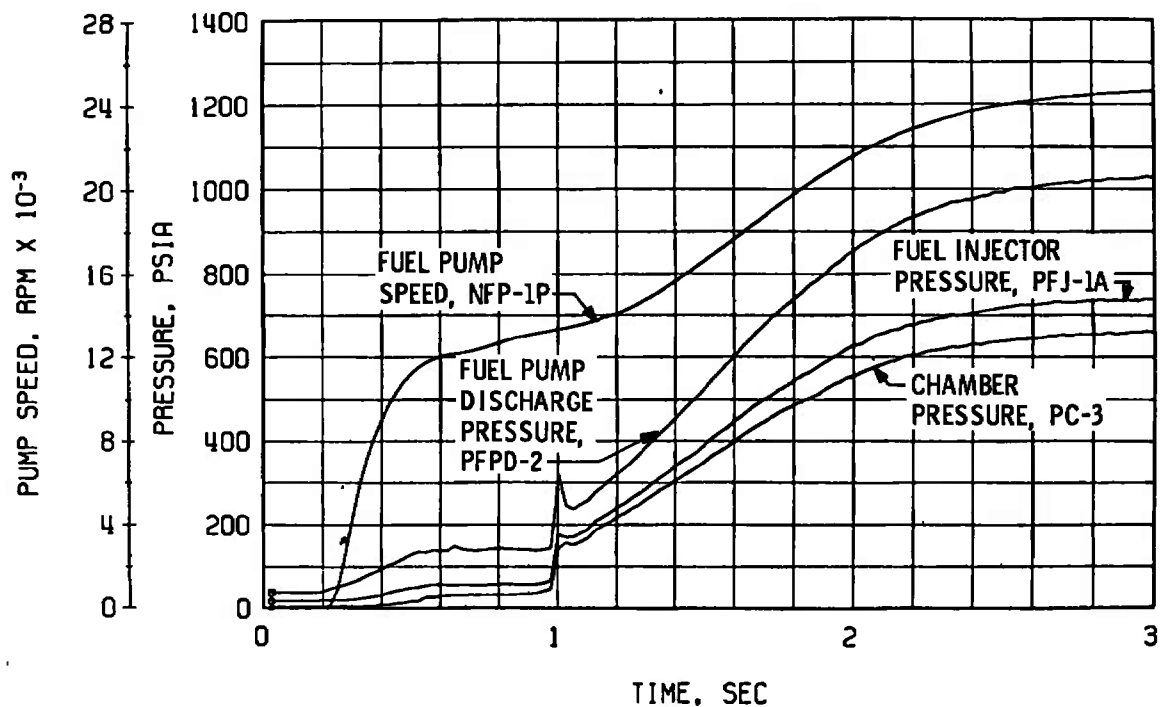


b. Crossover Duct, TTFD

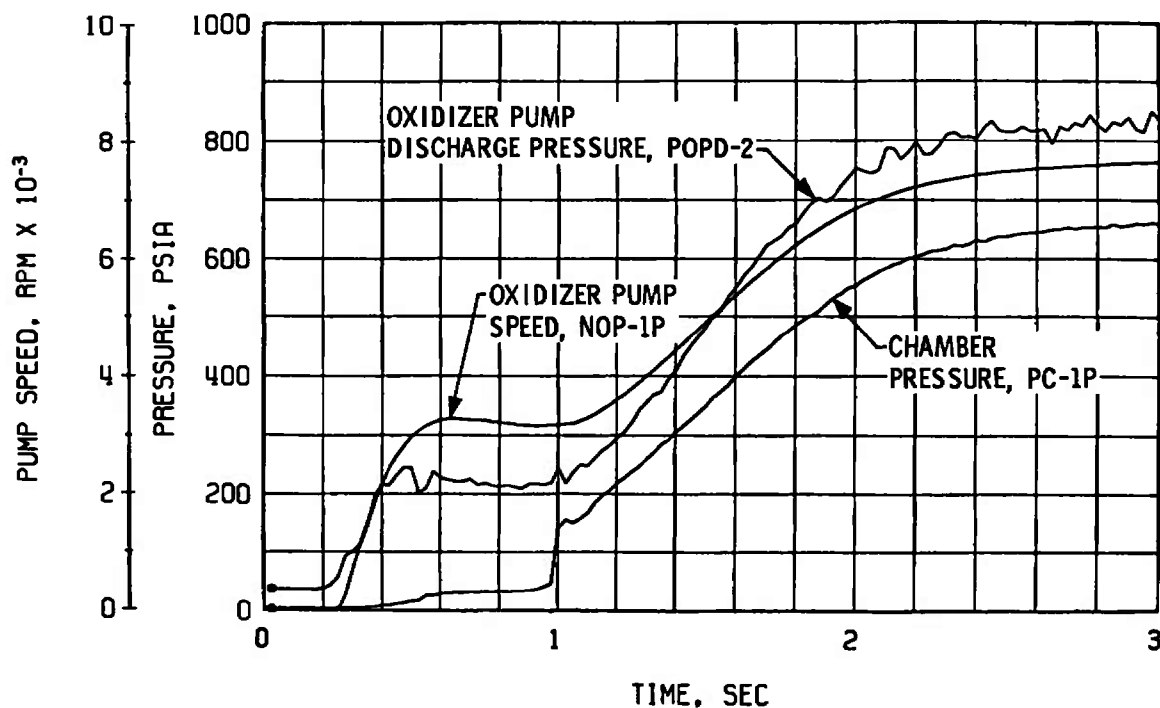


c. Thrust Chamber, TTC-1P

Fig. 29 Thermal Conditioning History of Engine Components, Firing 08A

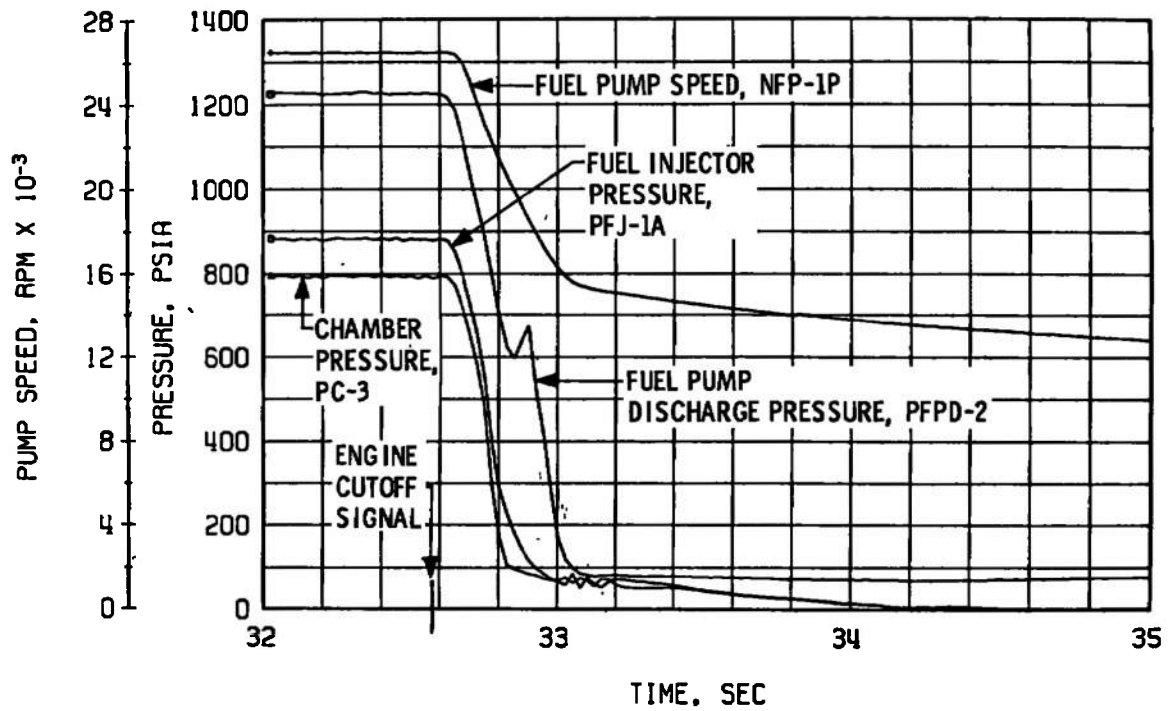


a. Thrust Chamber Fuel System, Start

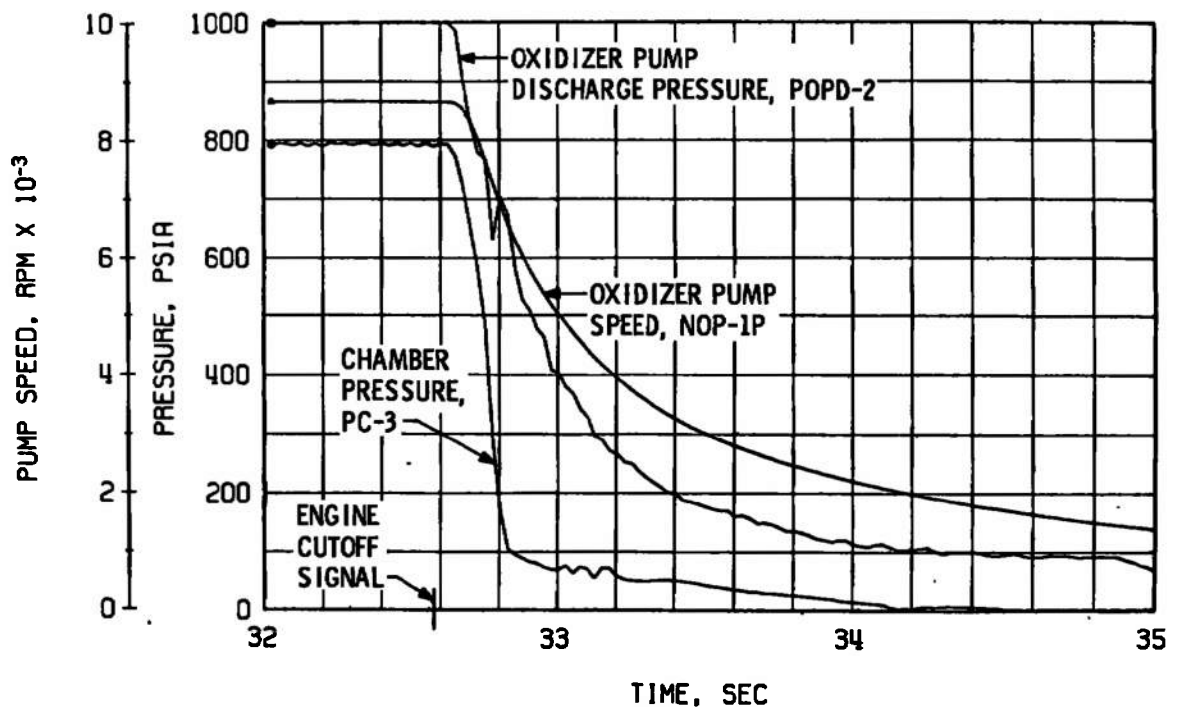


b. Thrust Chamber Oxidizer System, Start

Fig. 30 Engine Transient Operation, Firing 08A

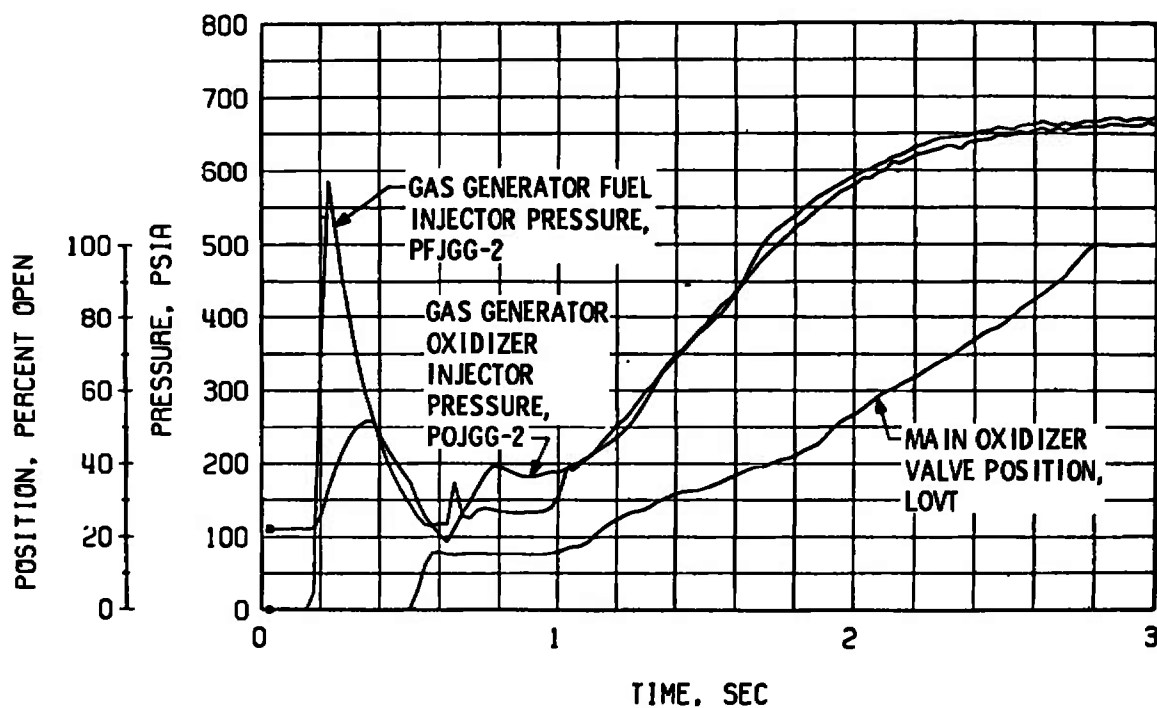


c. Thrust Chamber Fuel System, Shutdown

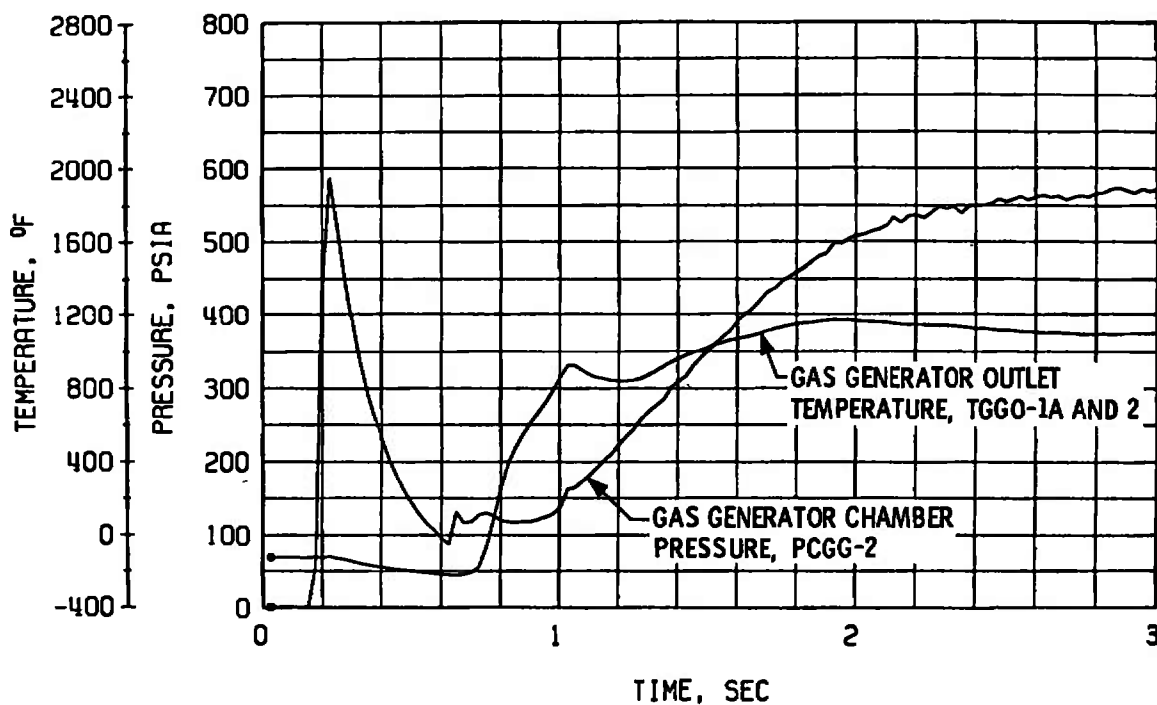


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 30 Continued

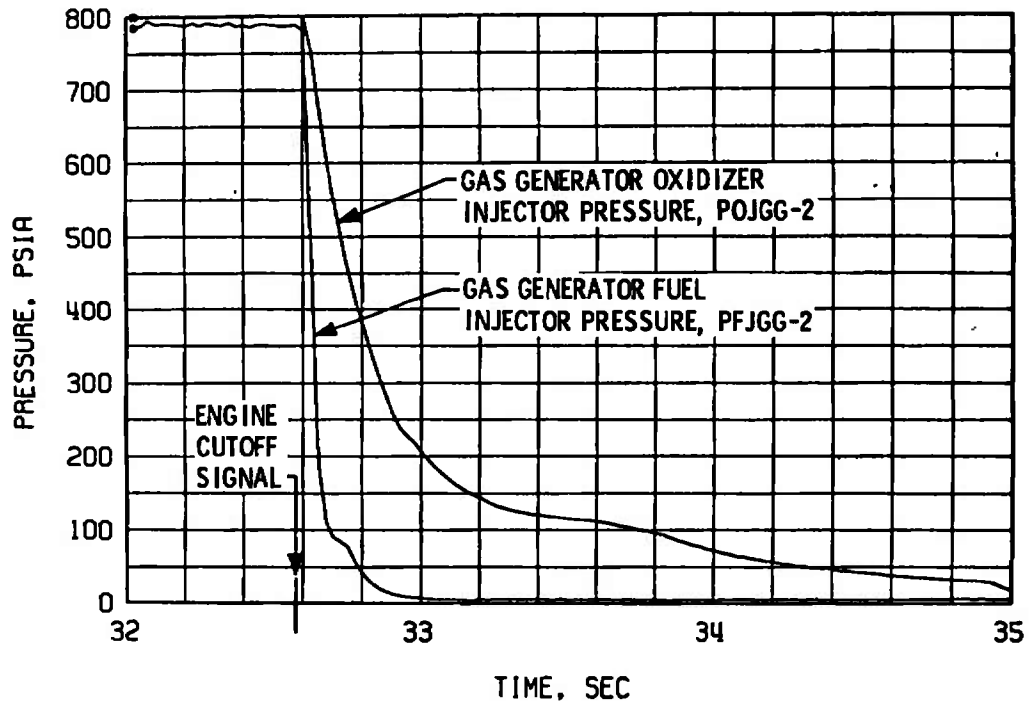


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

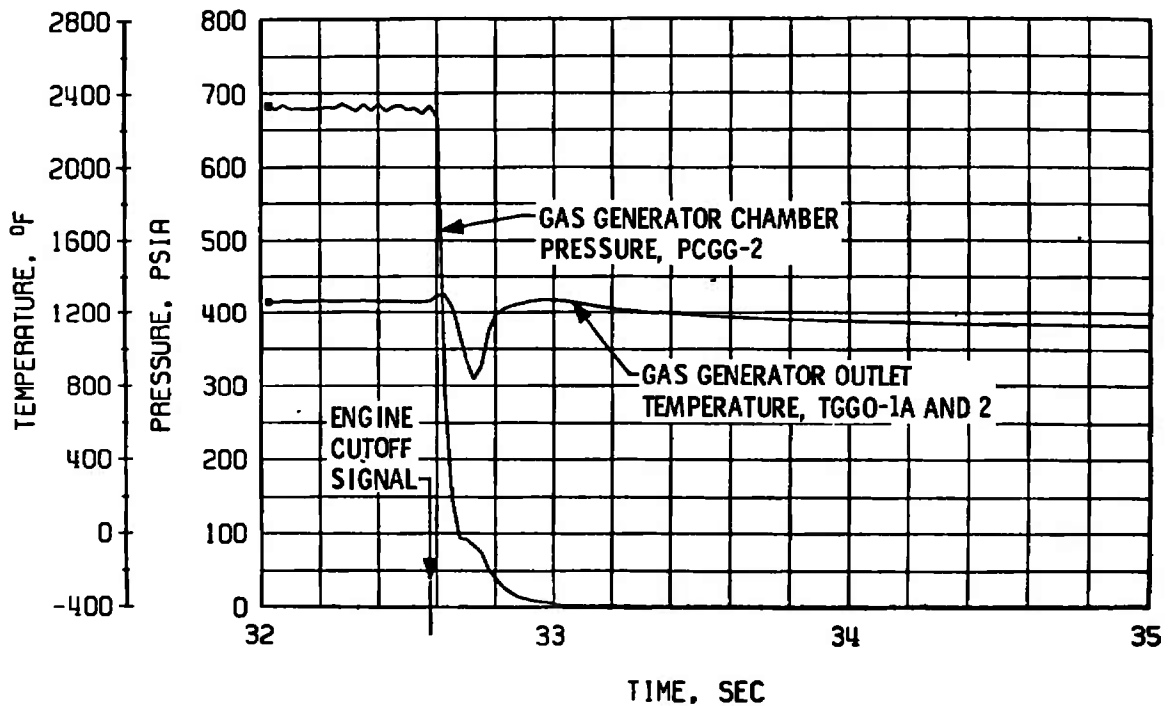


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 30 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 30 Concluded

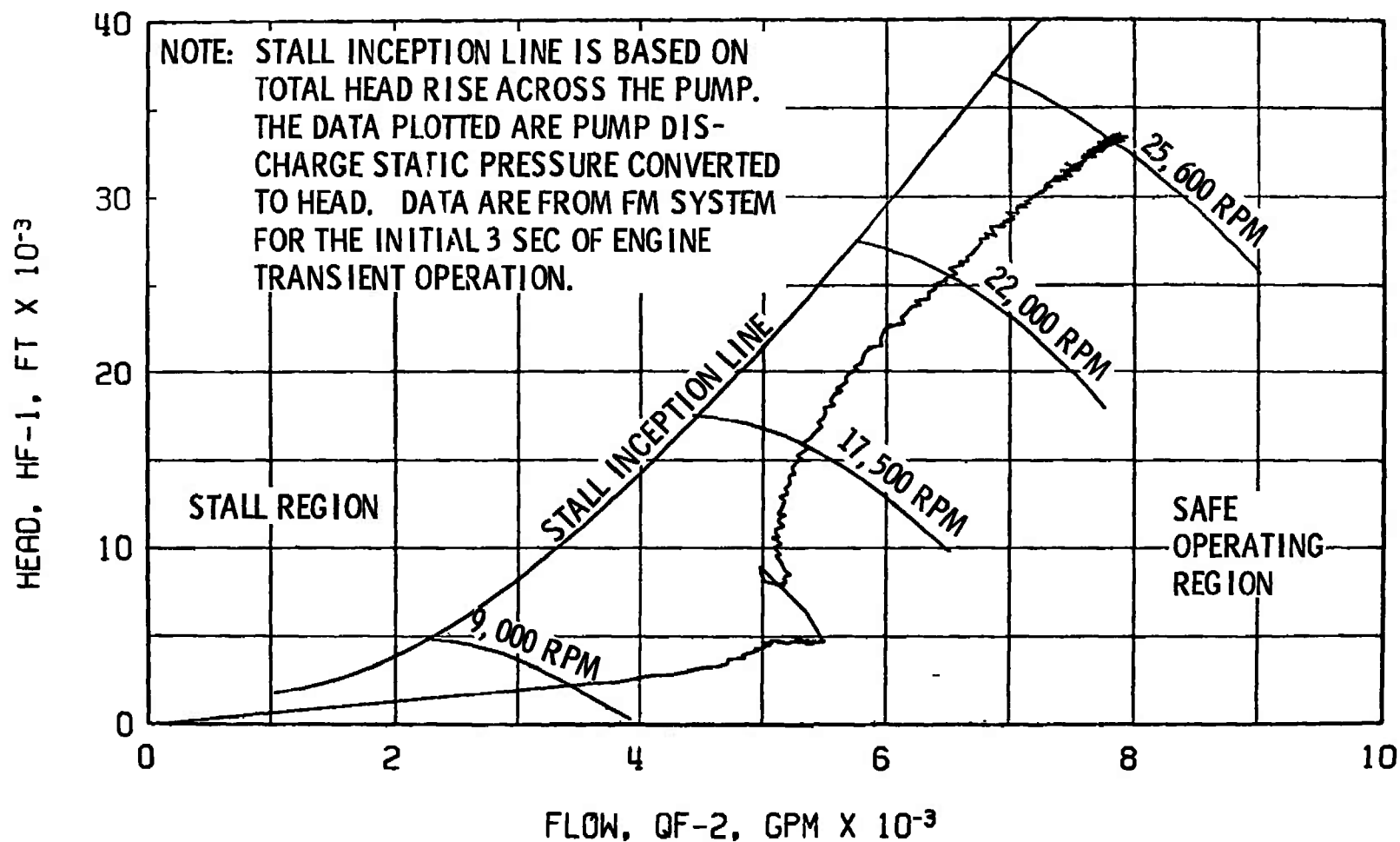


Fig. 31 Fuel Pump Start Transient Performance, Firing 08A

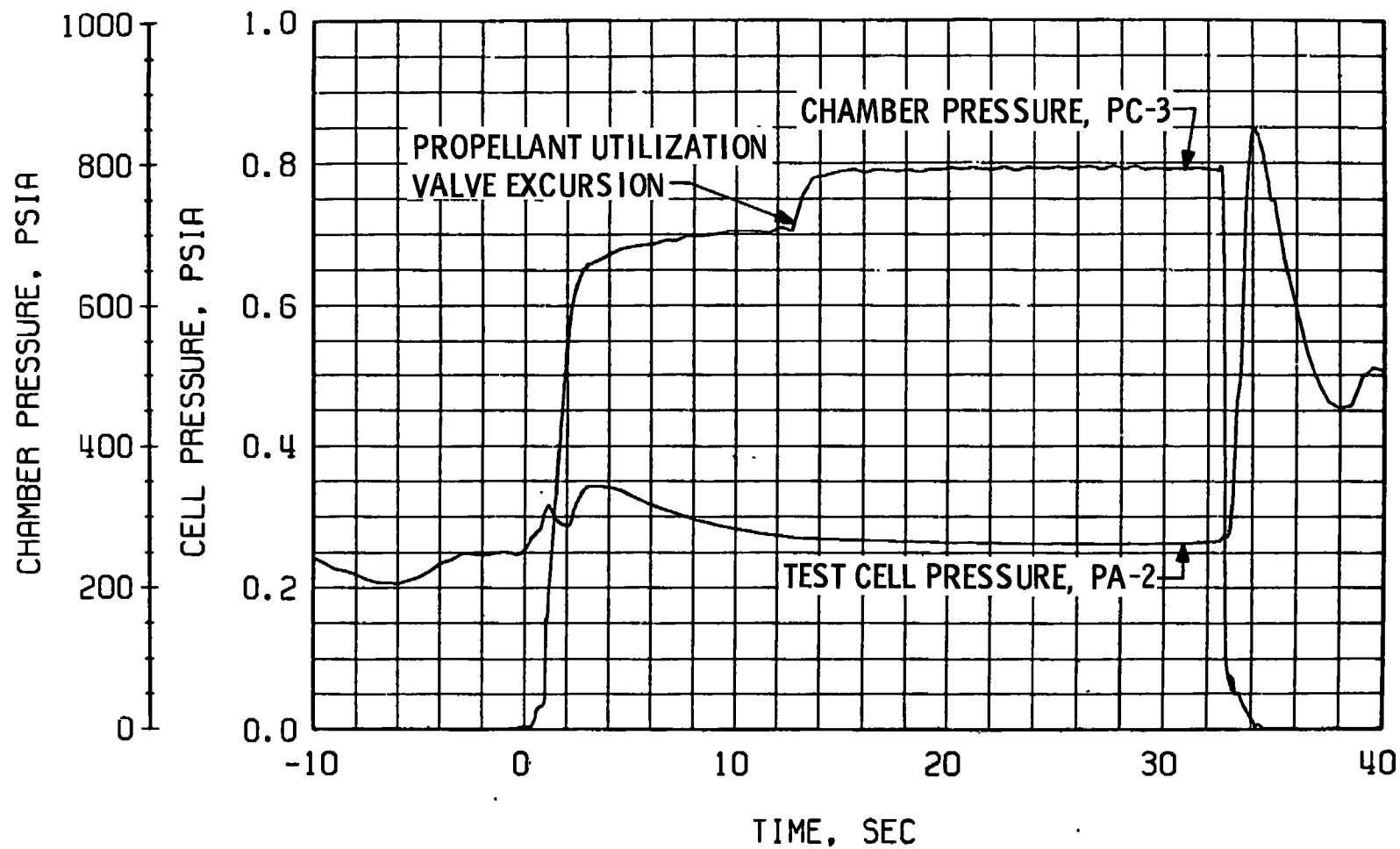
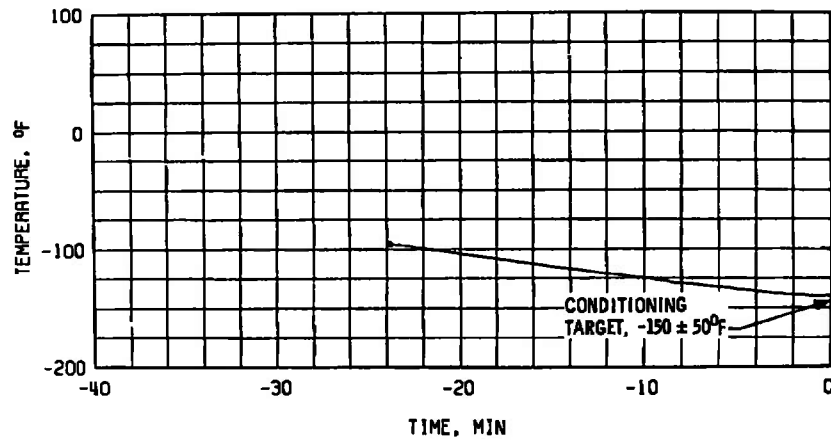
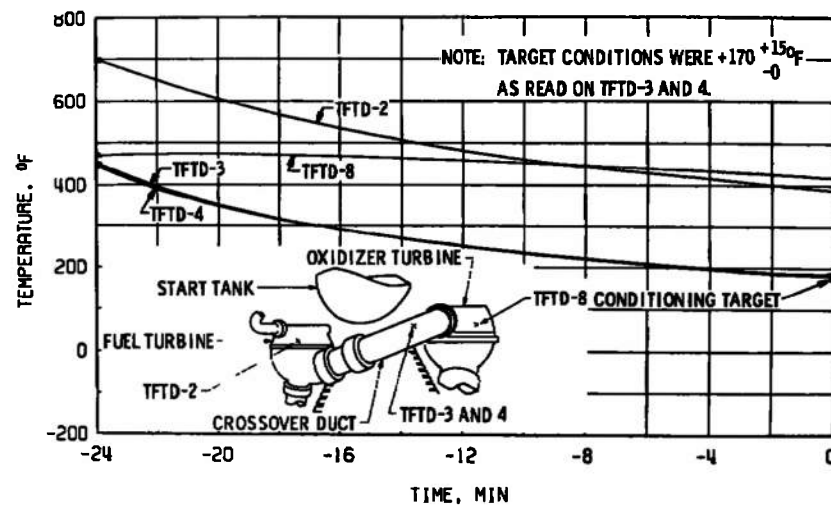


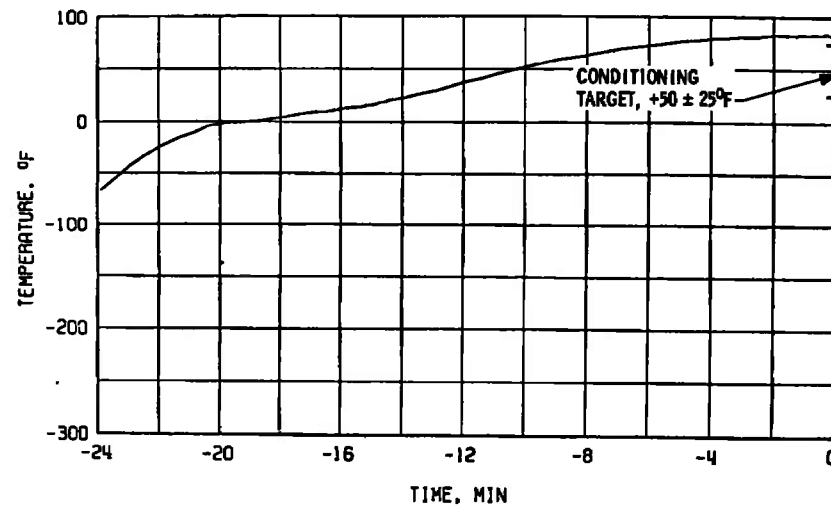
Fig. 32 Engine Ambient and Combustion Chamber Pressure, Firing 08A



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1



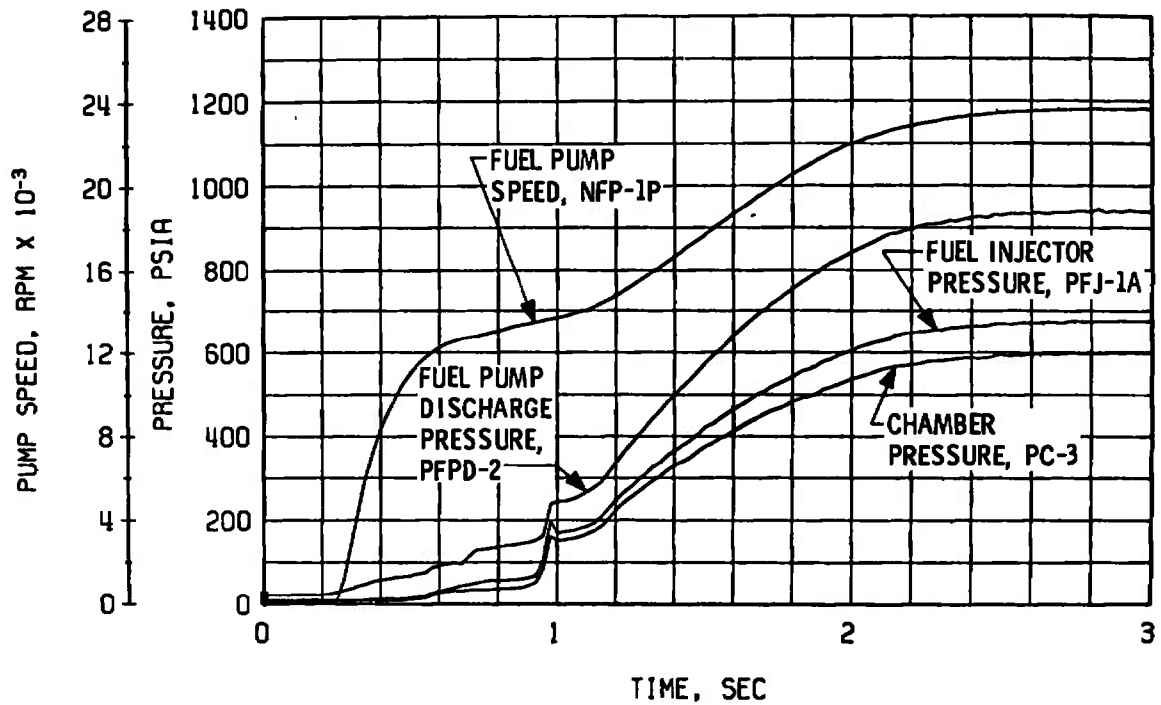
b. Crossover Duct, TTFD



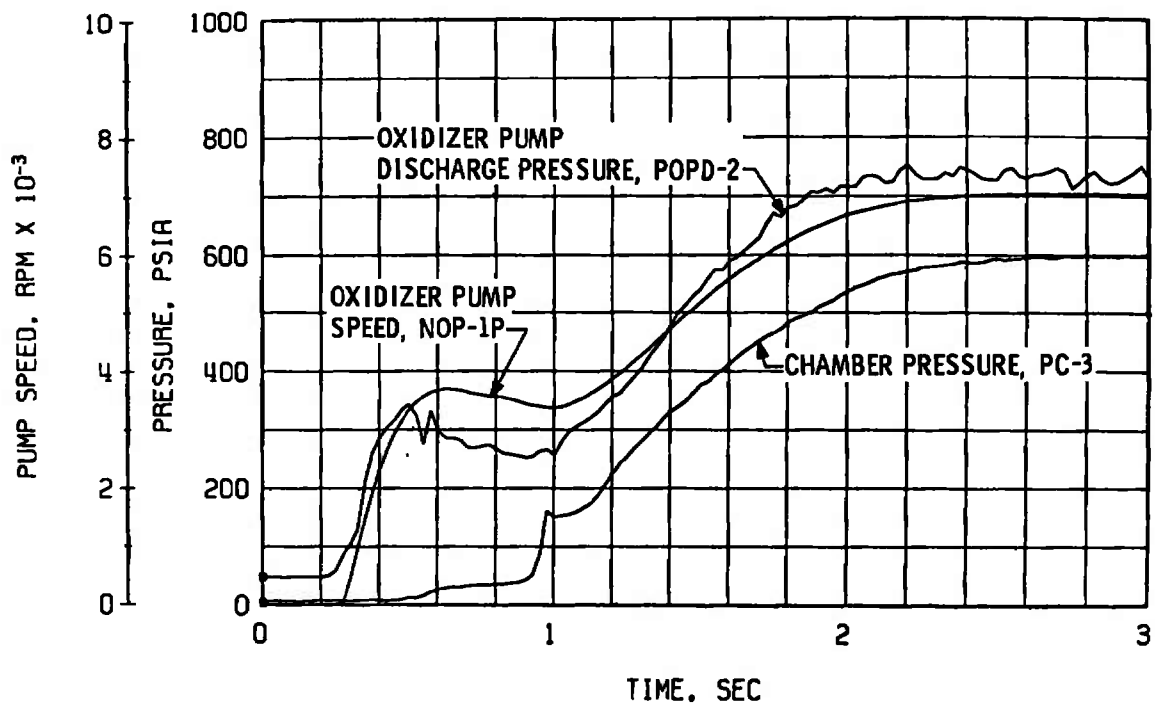
c. Thrust Chamber, TTC-1P

Fig. 33 Thermal Conditioning History of Engine Components, Firing 08B



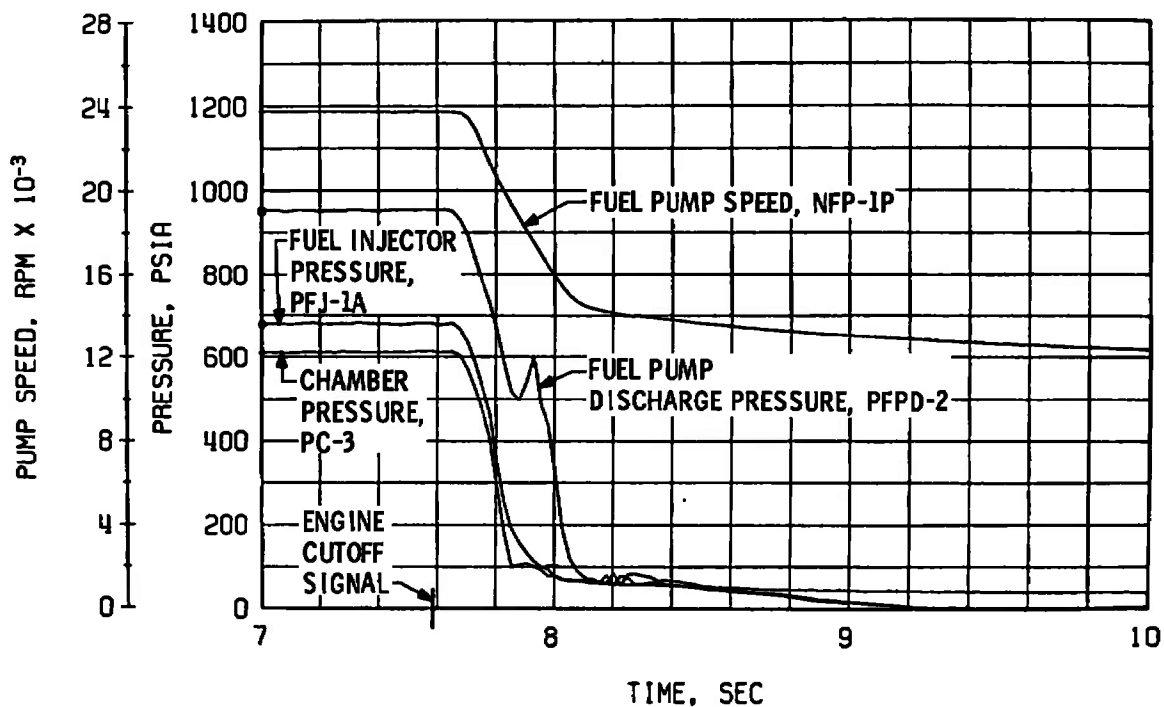


a. Thrust Chamber Fuel System, Start

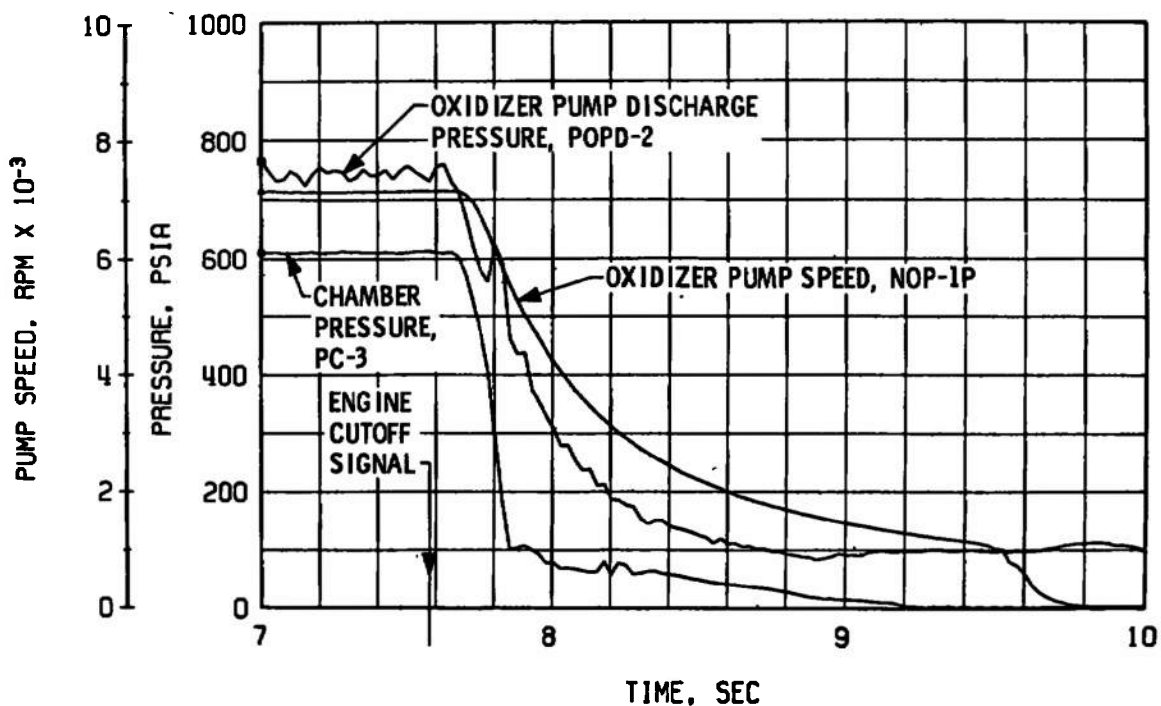


b. Thrust Chamber Oxidizer System, Start

Fig. 34 Engine Transient Operation, Firing 08B

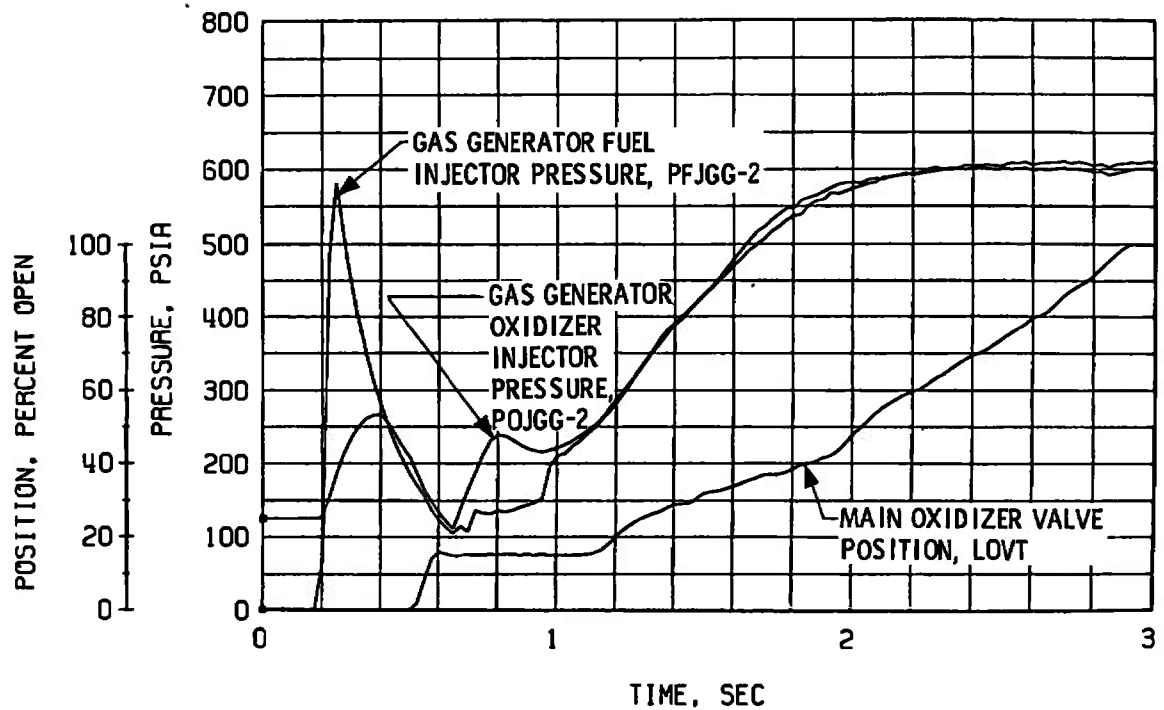


c. Thrust Chamber Fuel System, Shutdown

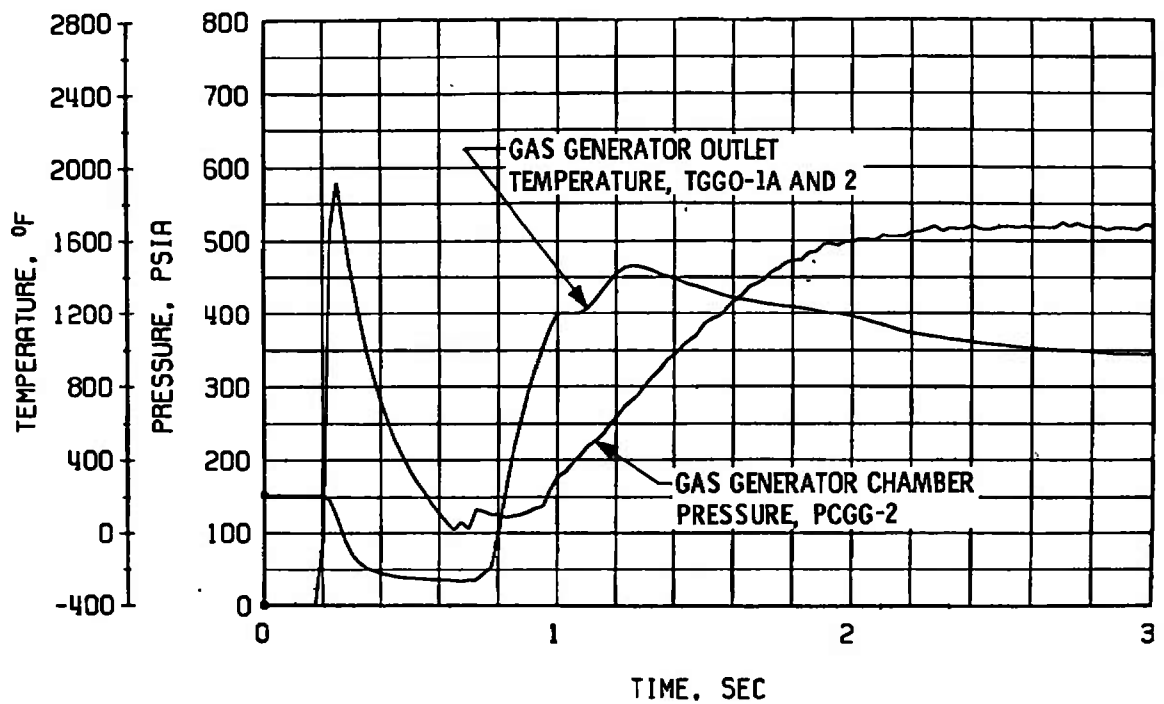


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 34 Continued

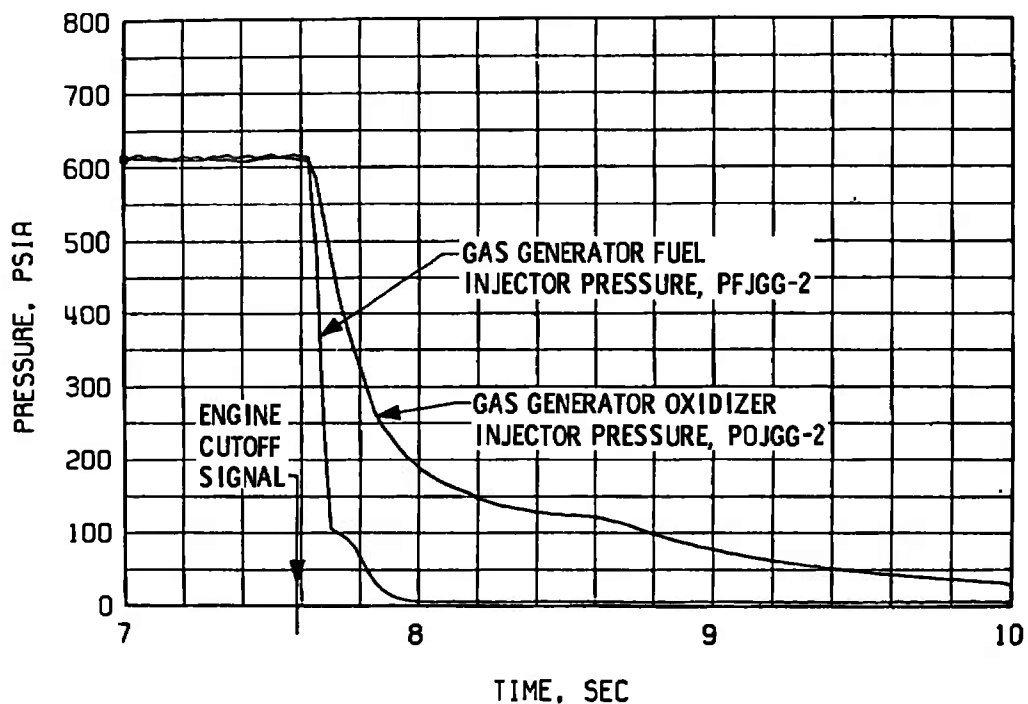


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

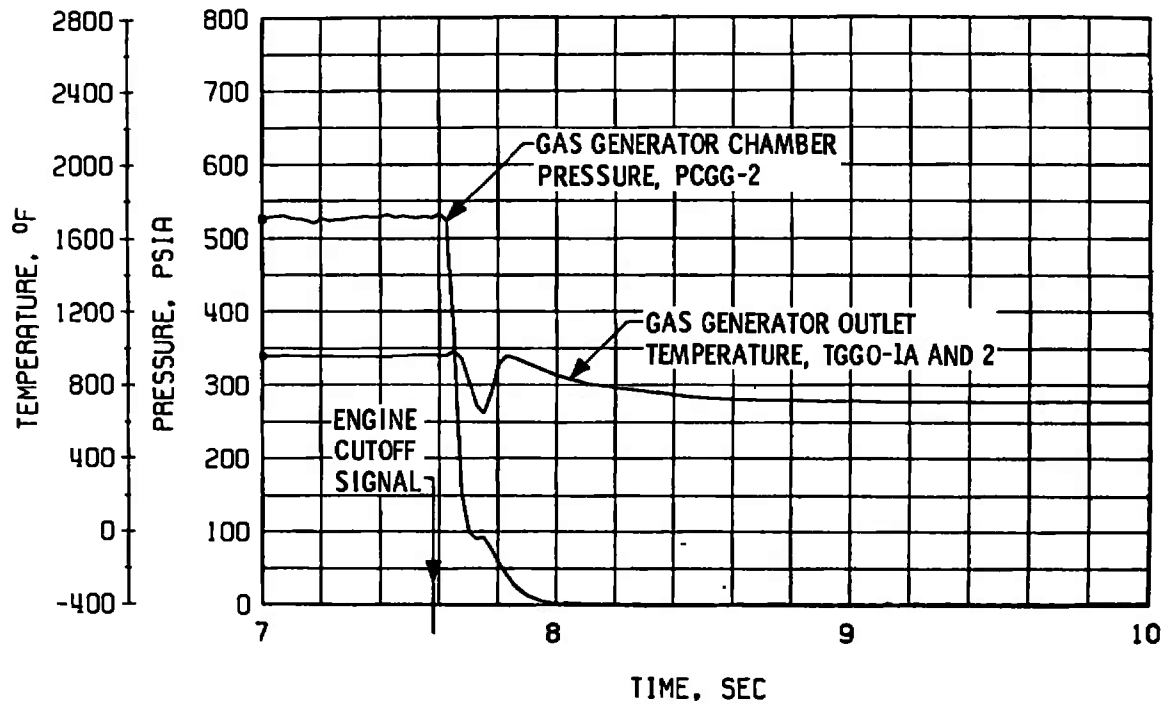


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 34 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 34 Concluded

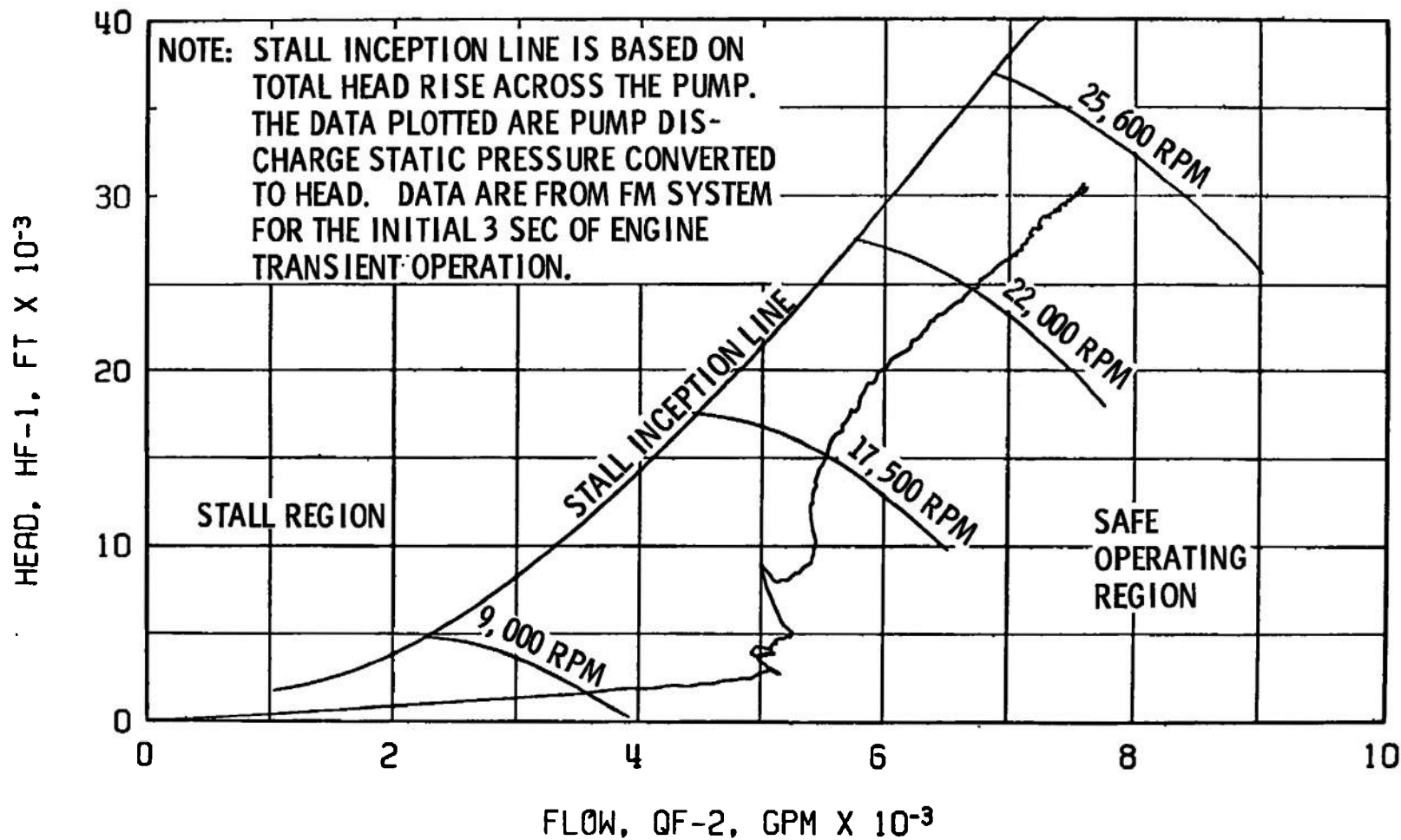


Fig. 35 Fuel Pump Start Transient Performance, Firing 08B

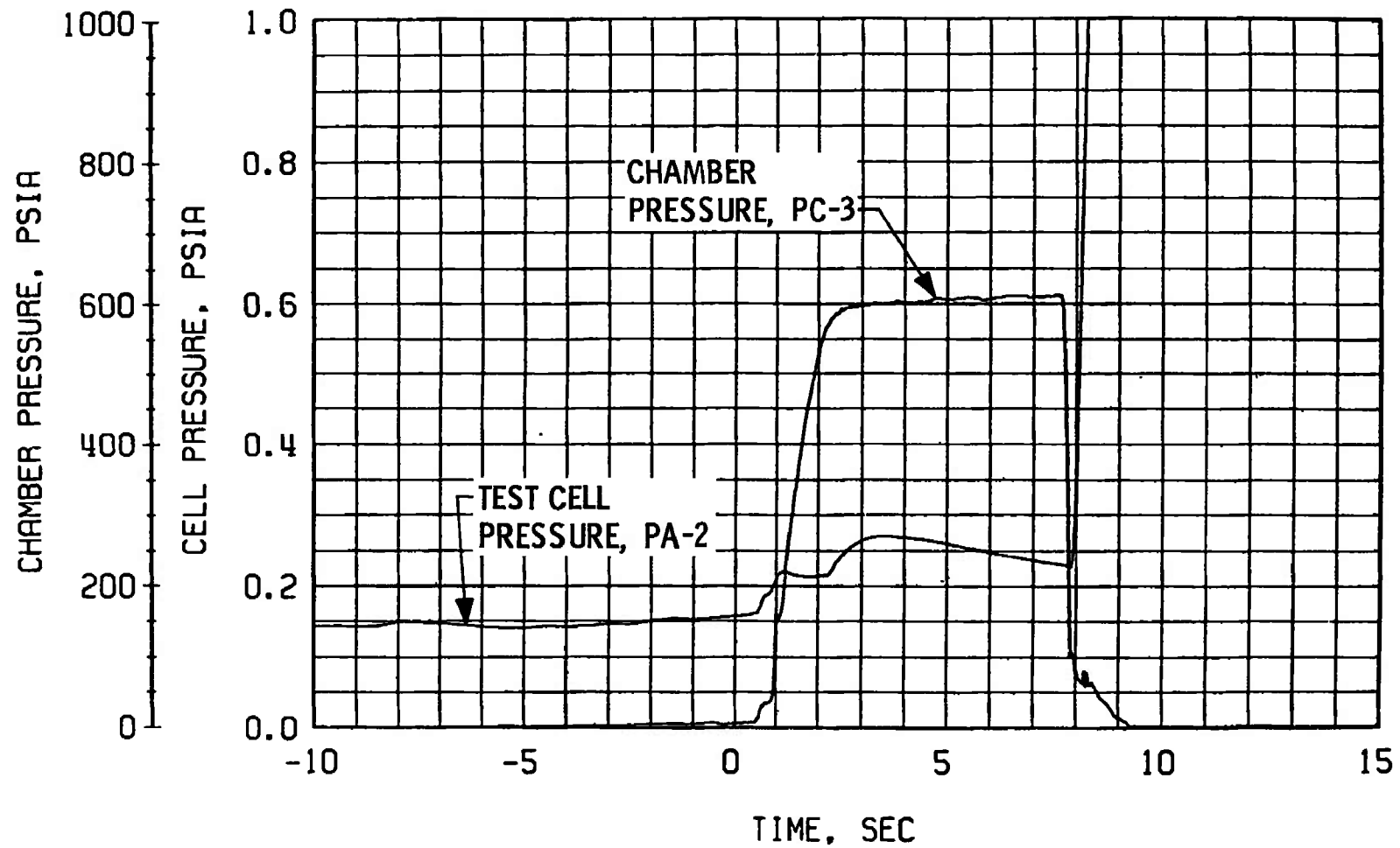
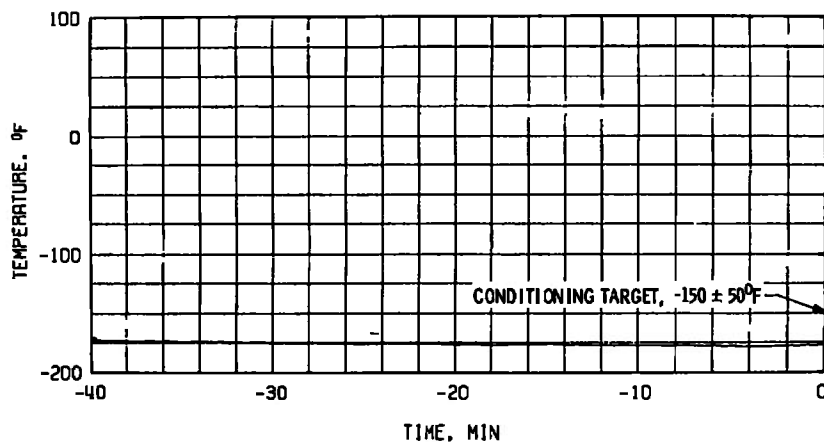
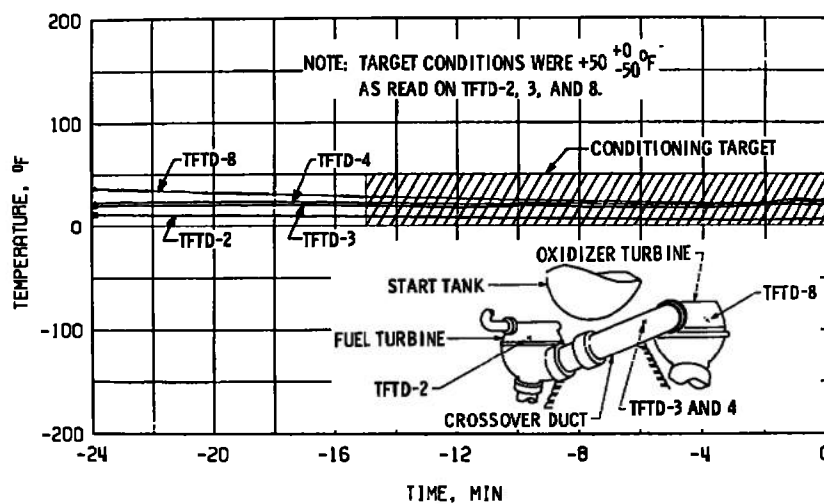


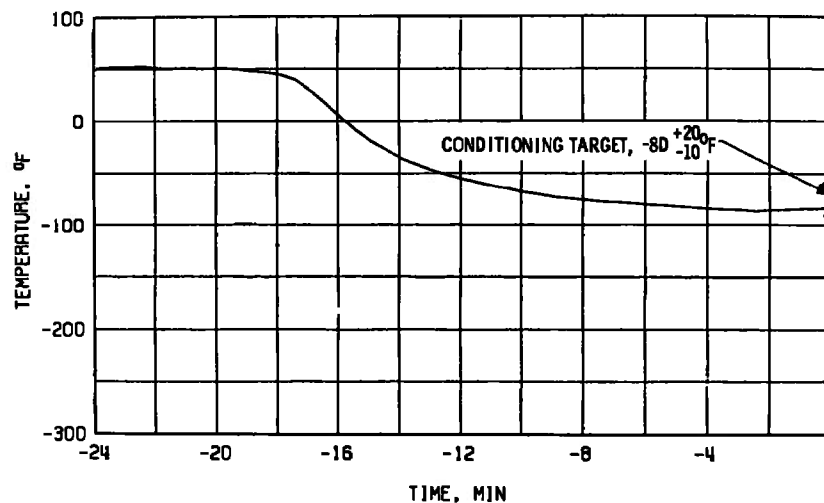
Fig. 36 Engine Ambient and Combustion Chamber Pressure, Firing 08B



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

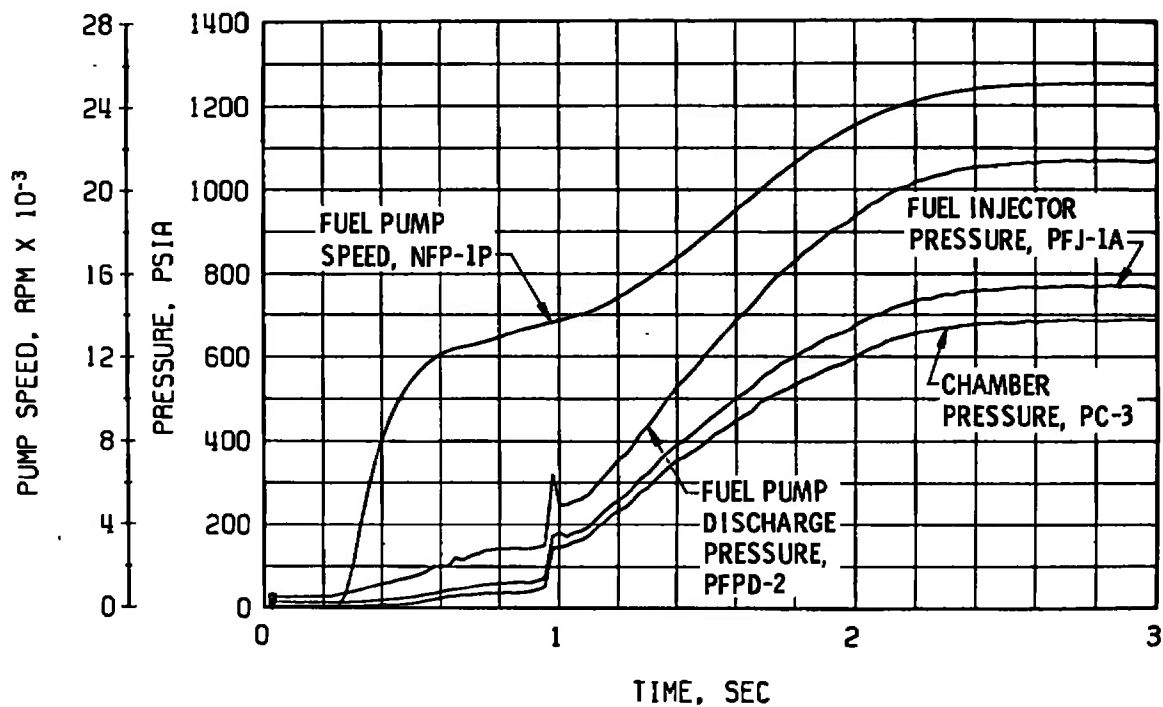


b. Crossover Duct, TTFD

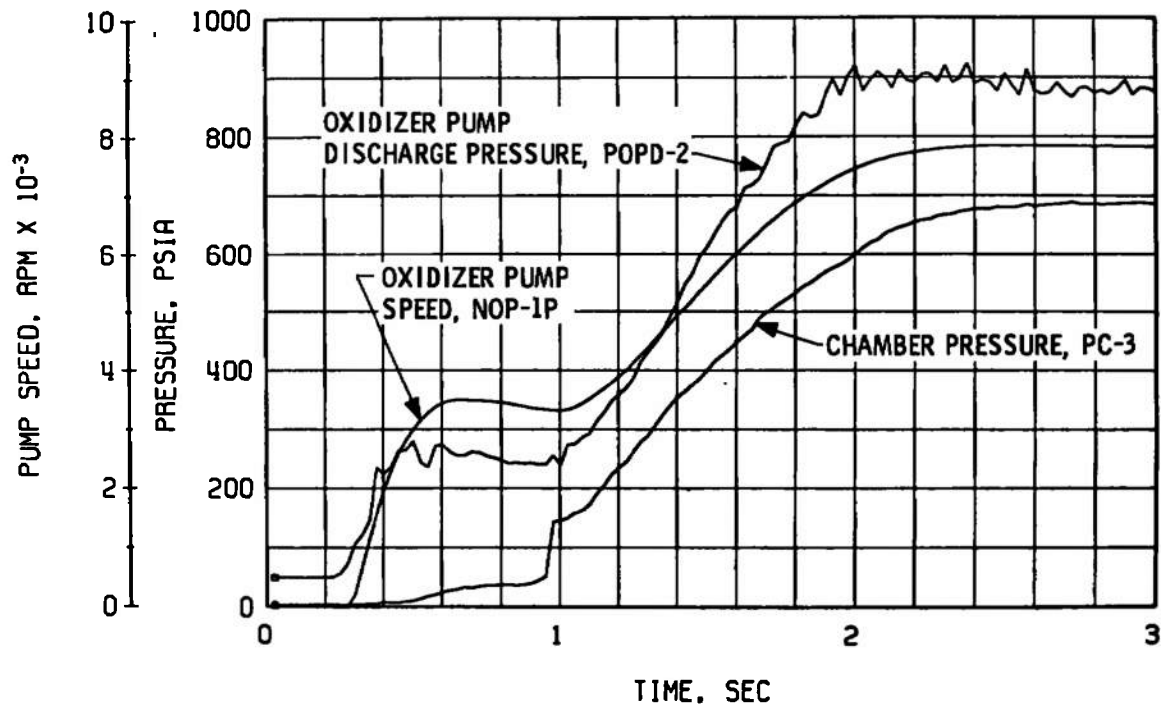


c. Thrust Chamber, TTC-1P

Fig. 37 Thermal Conditioning History of Engine Components, Firing 08C



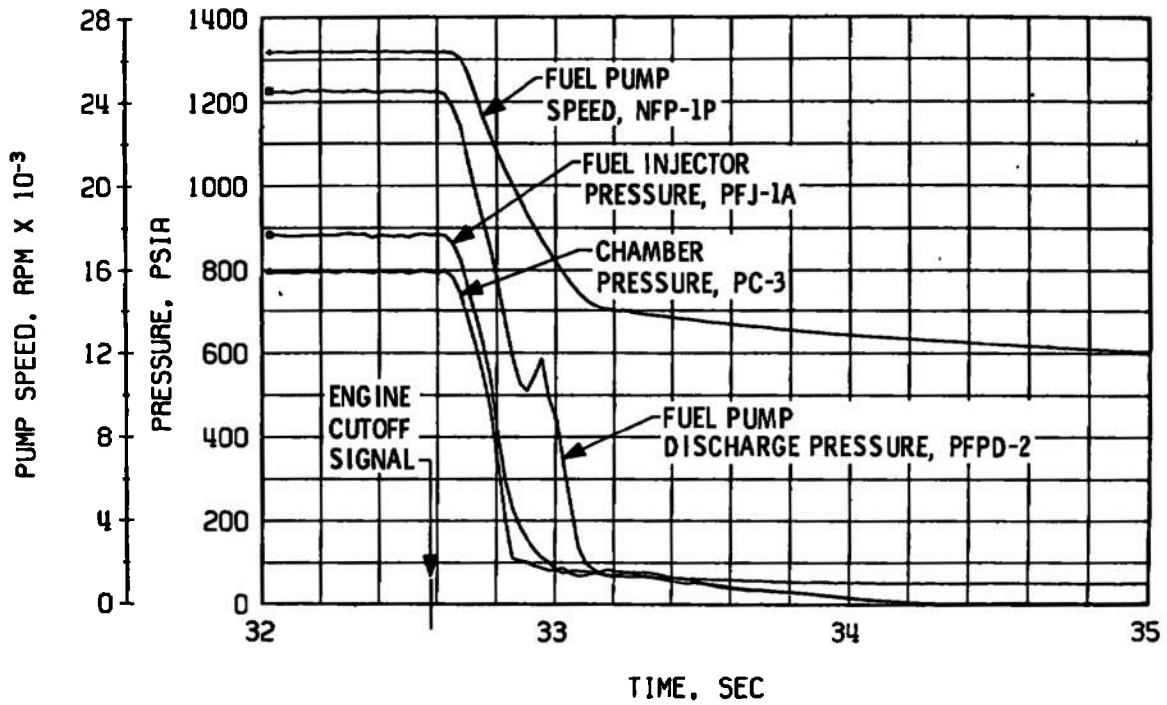
a. Thrust Chamber Fuel System, Start



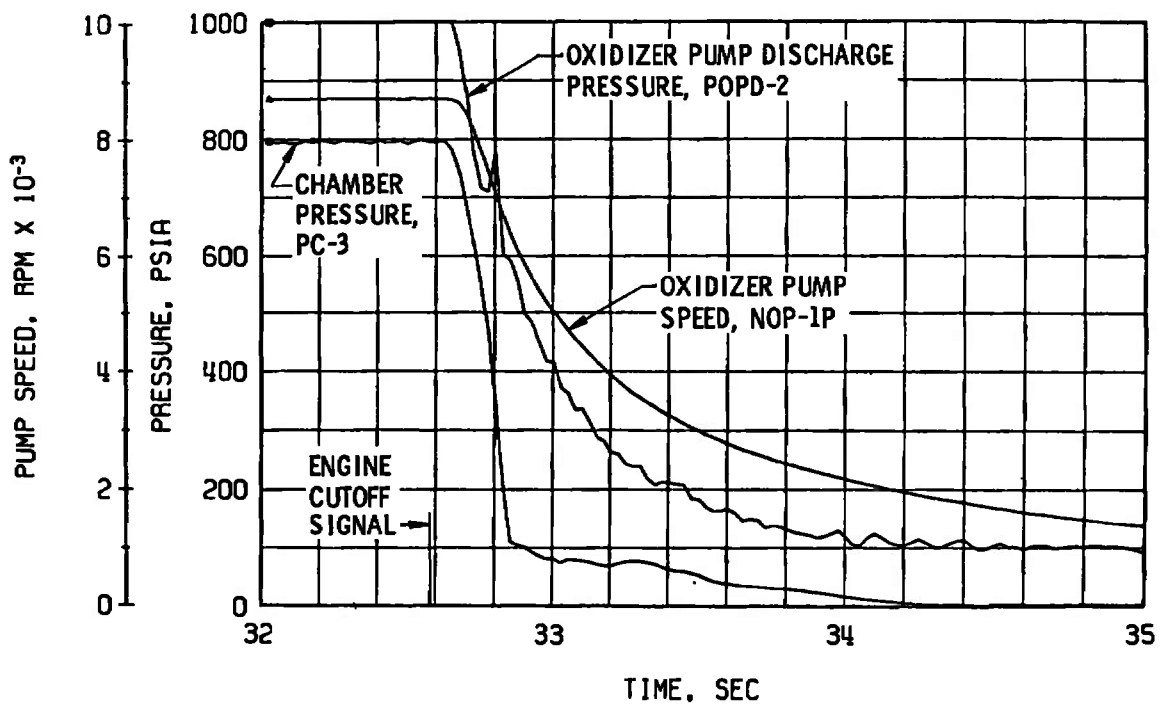
b. Thrust Chamber Oxidizer System, Start

Fig. 38 Engine Transient Operation, Firing 08C



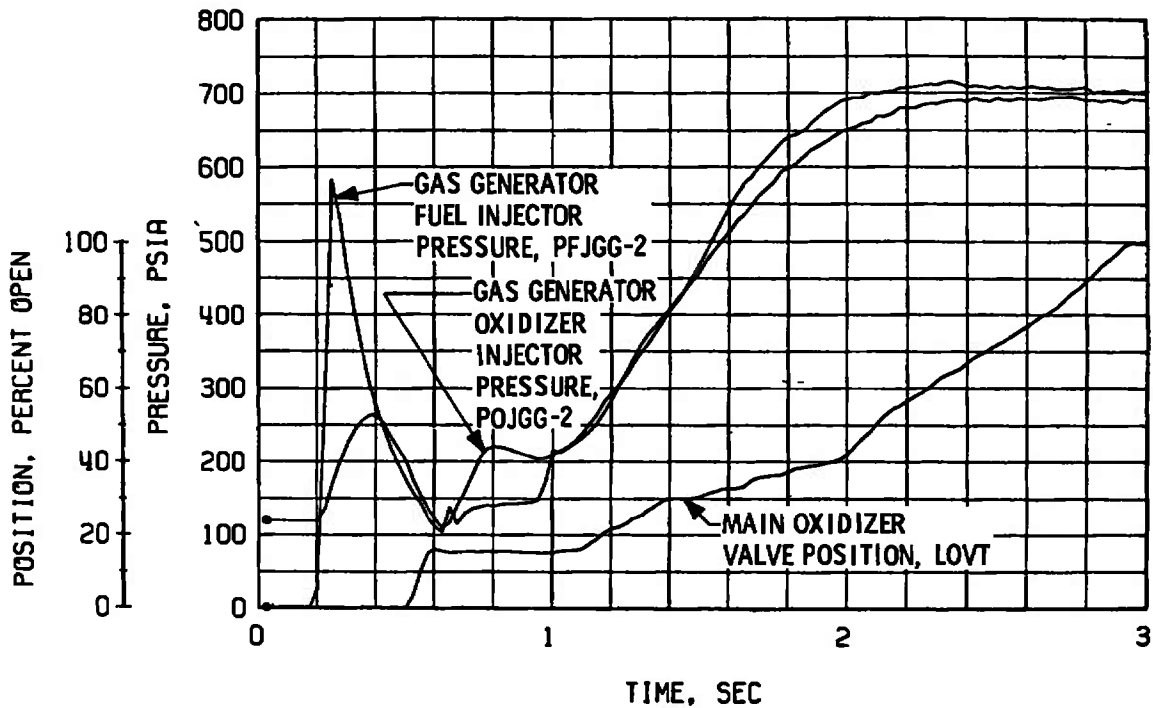


c. Thrust Chamber Fuel System, Shutdown

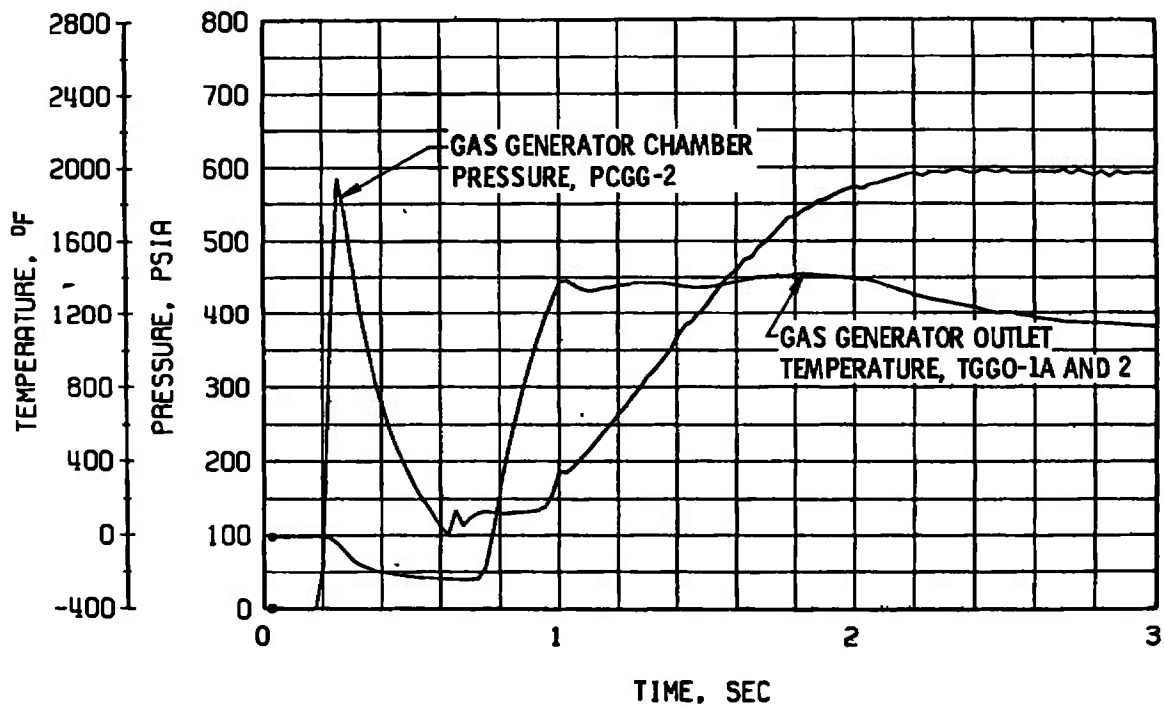


d. Thrust Chamber Oxidizer System, Shutdown

Fig. 38 Continued

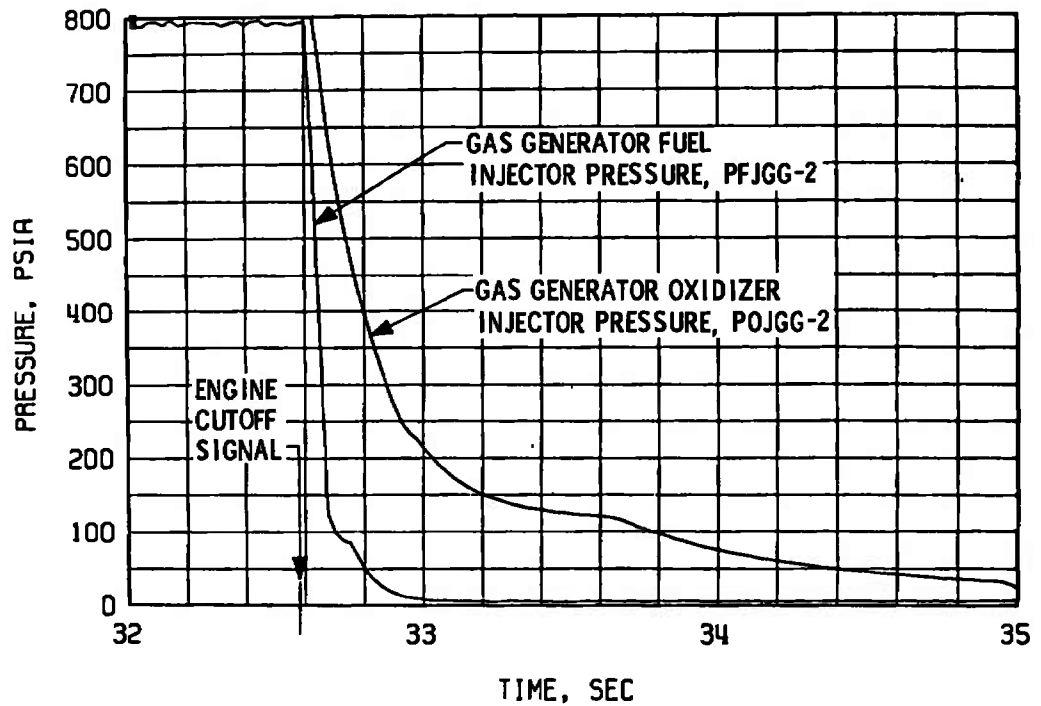


e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

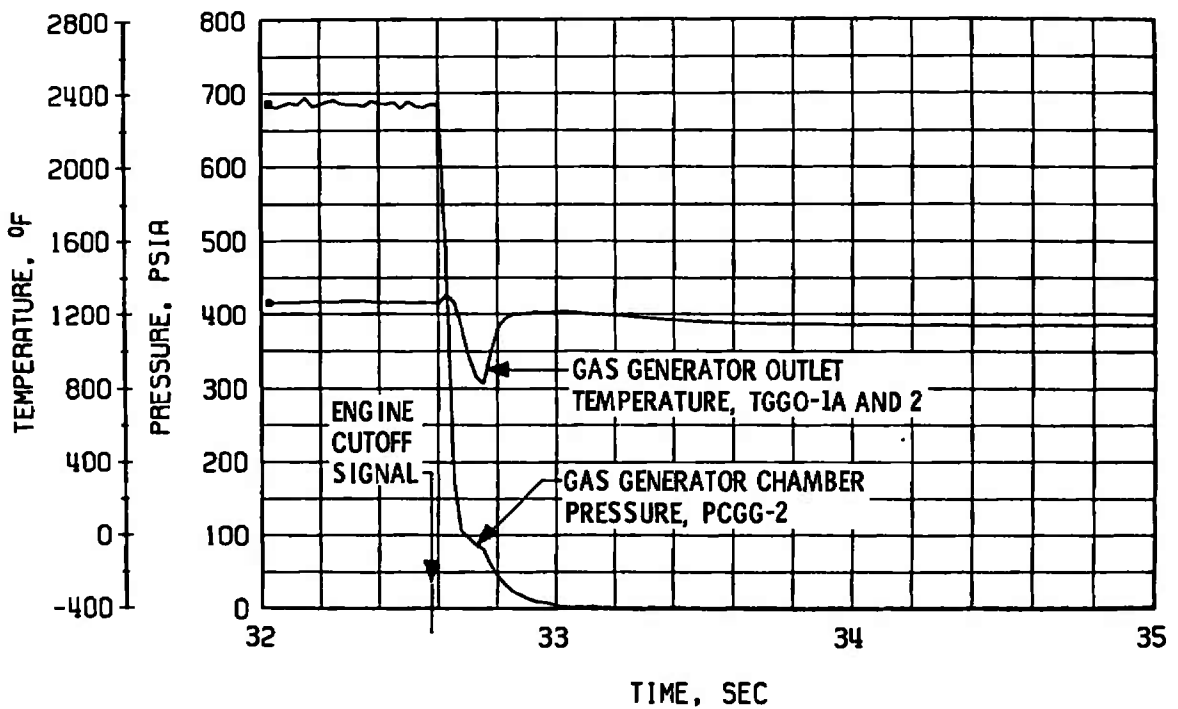


f. Gas Generator Chamber Pressure and Temperature, Start

Fig. 38 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 38 Concluded

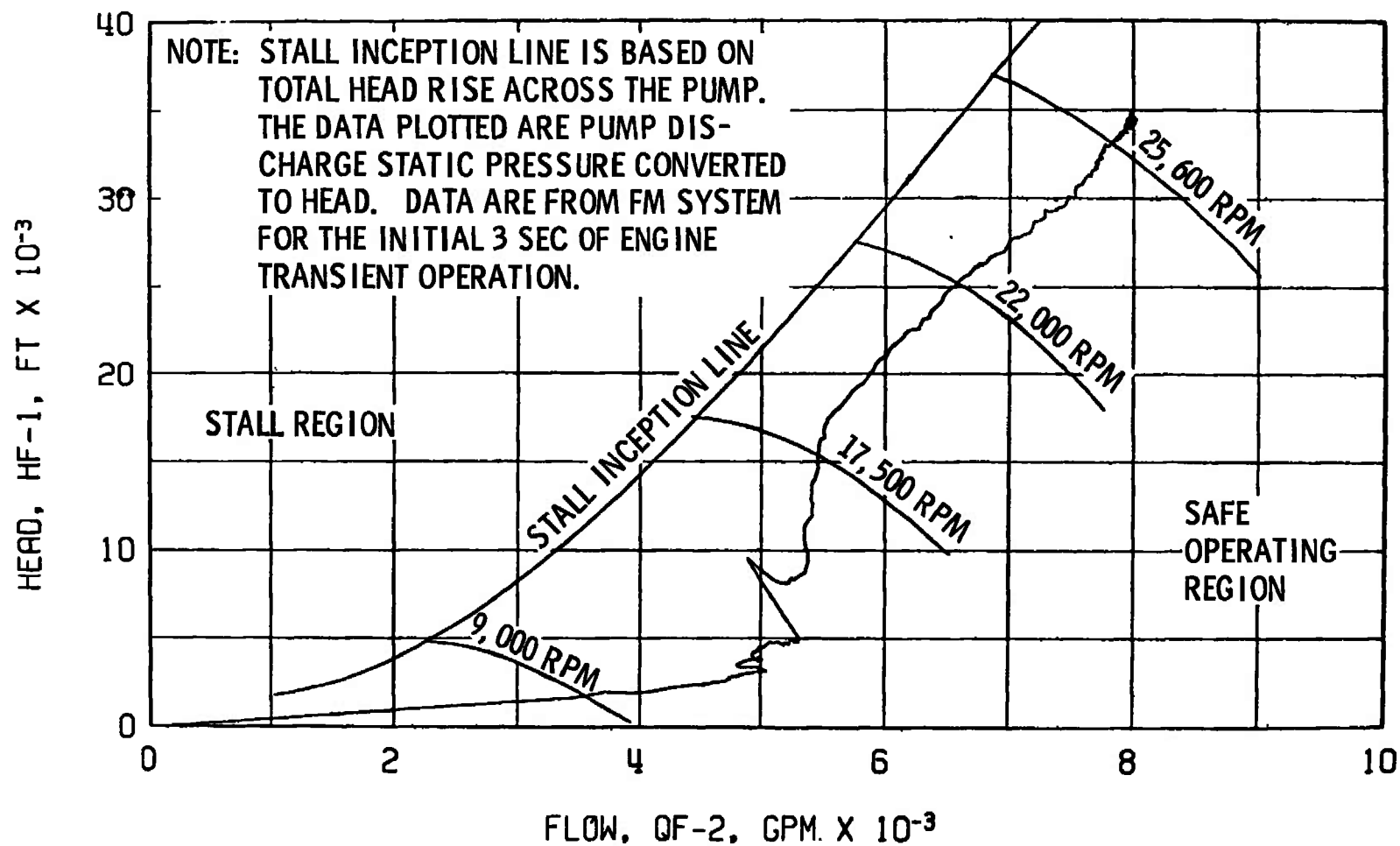


Fig. 39 Fuel Pump Start Transient Performance, Firing 08C

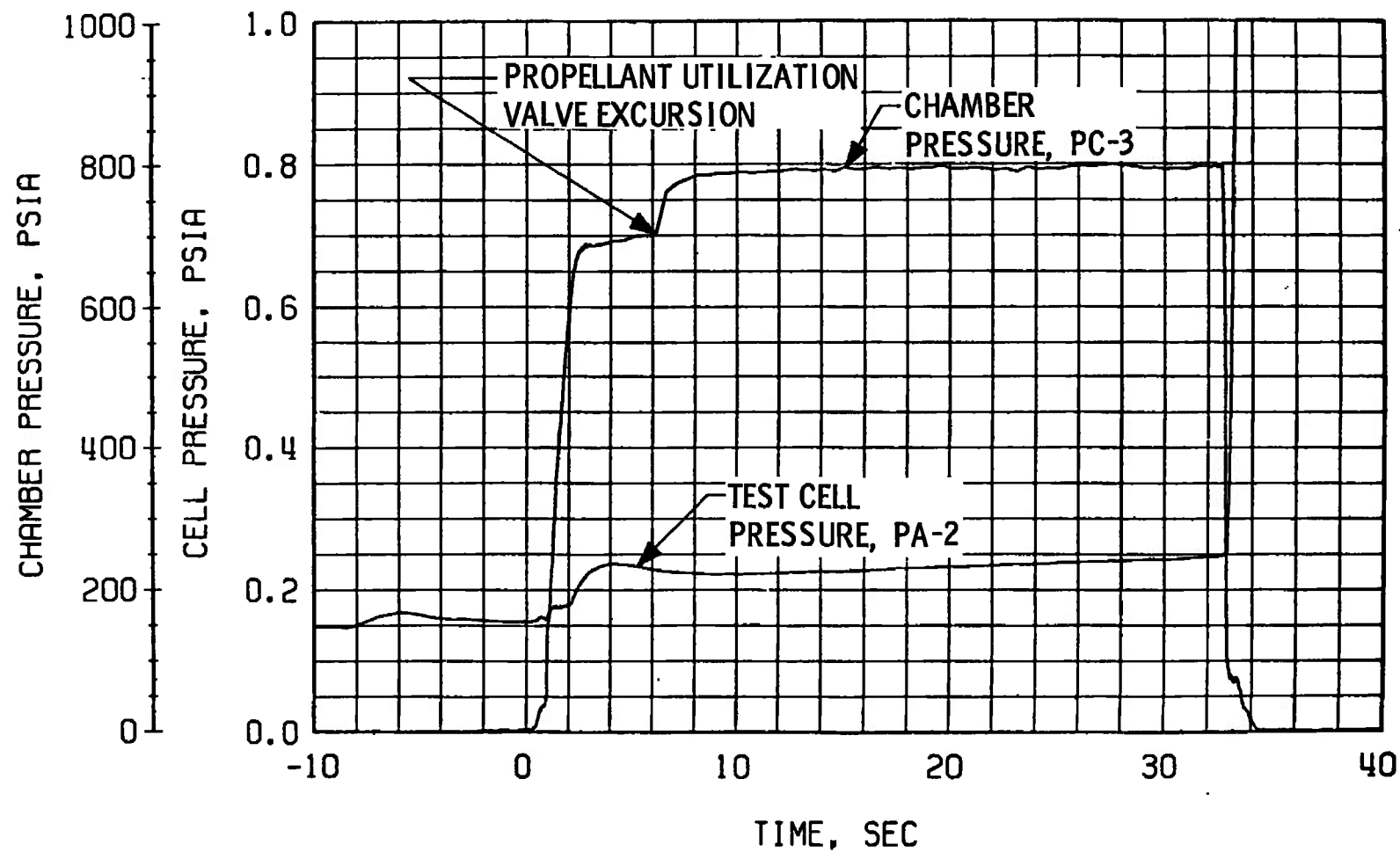
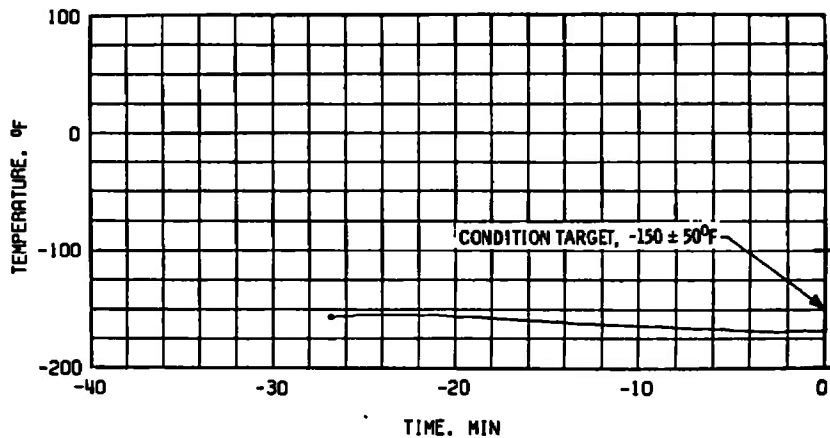
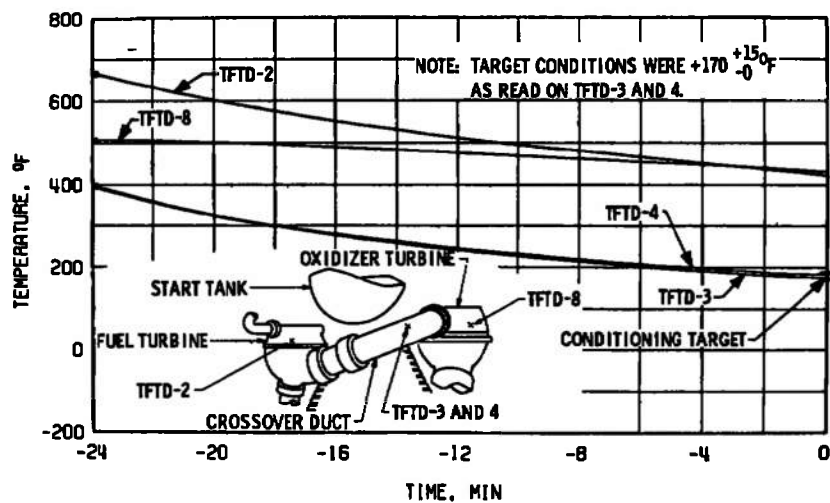


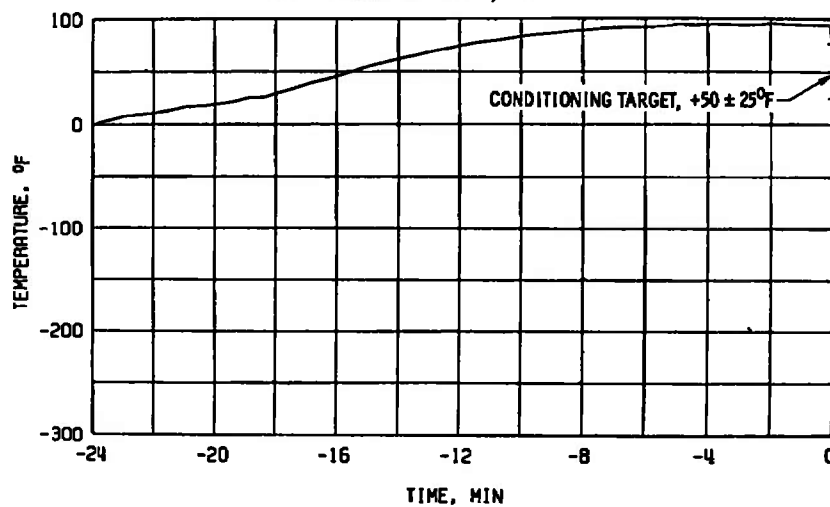
Fig. 40 Engine Ambient and Combustion Chamber Pressure, Firing 08C



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

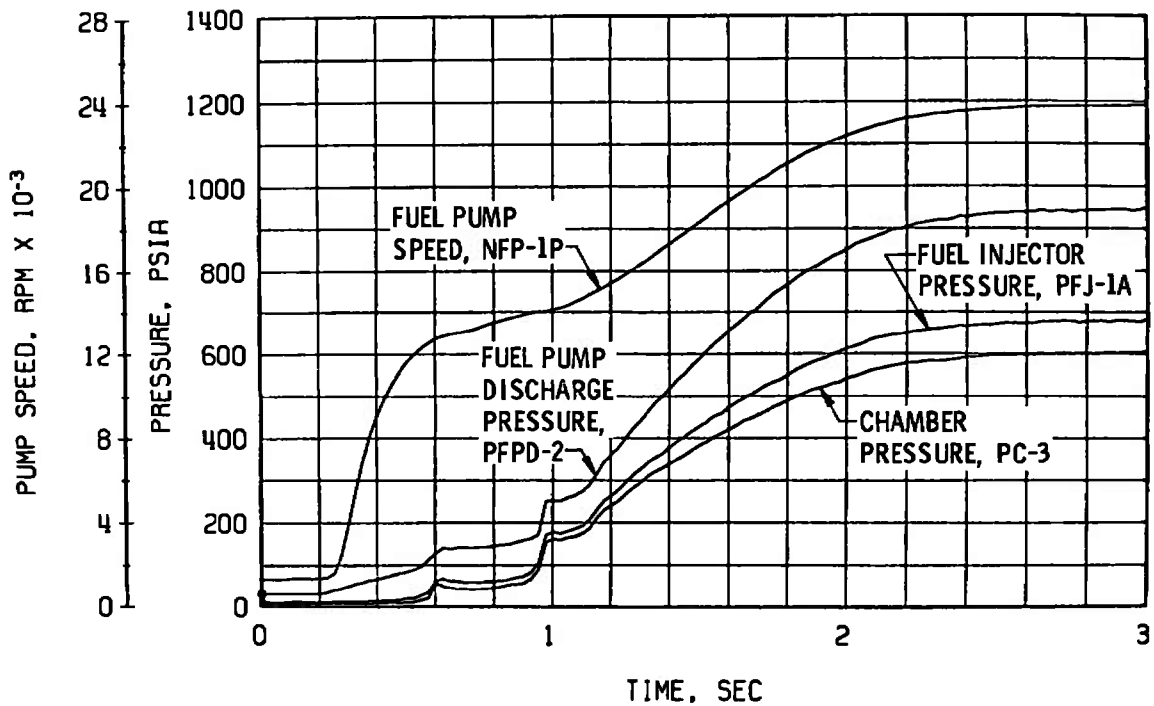


b. Crossover Duct, TTFD

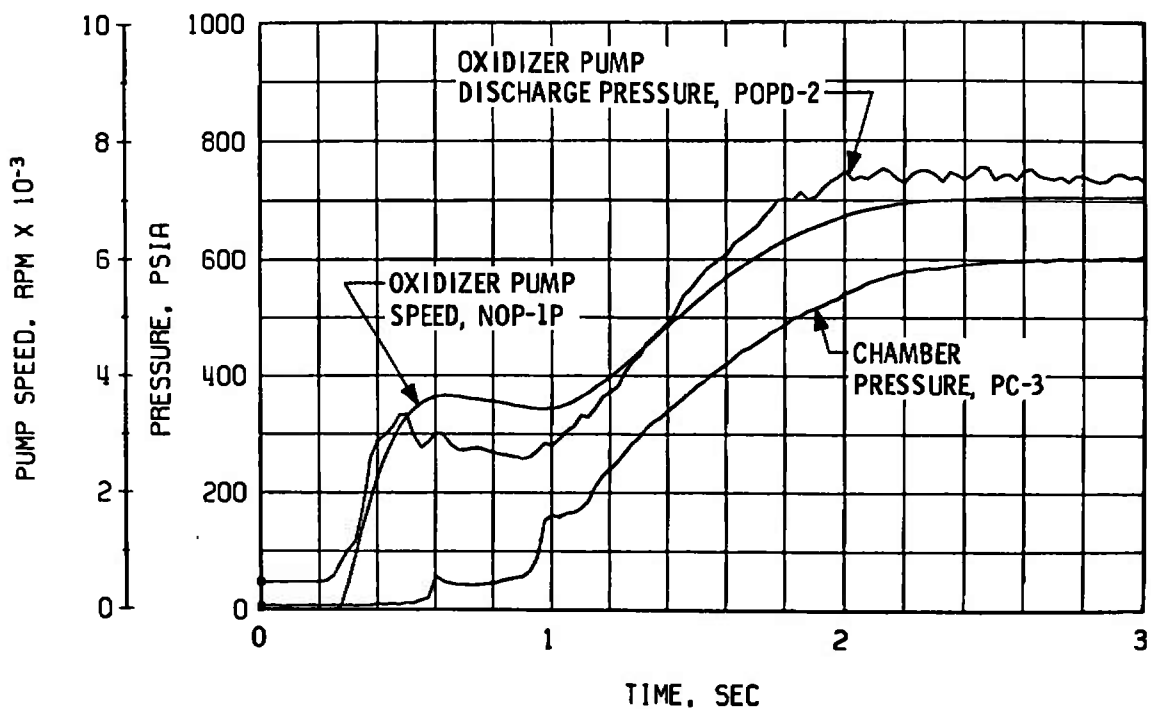


c. Thrust Chamber, TTC-1P

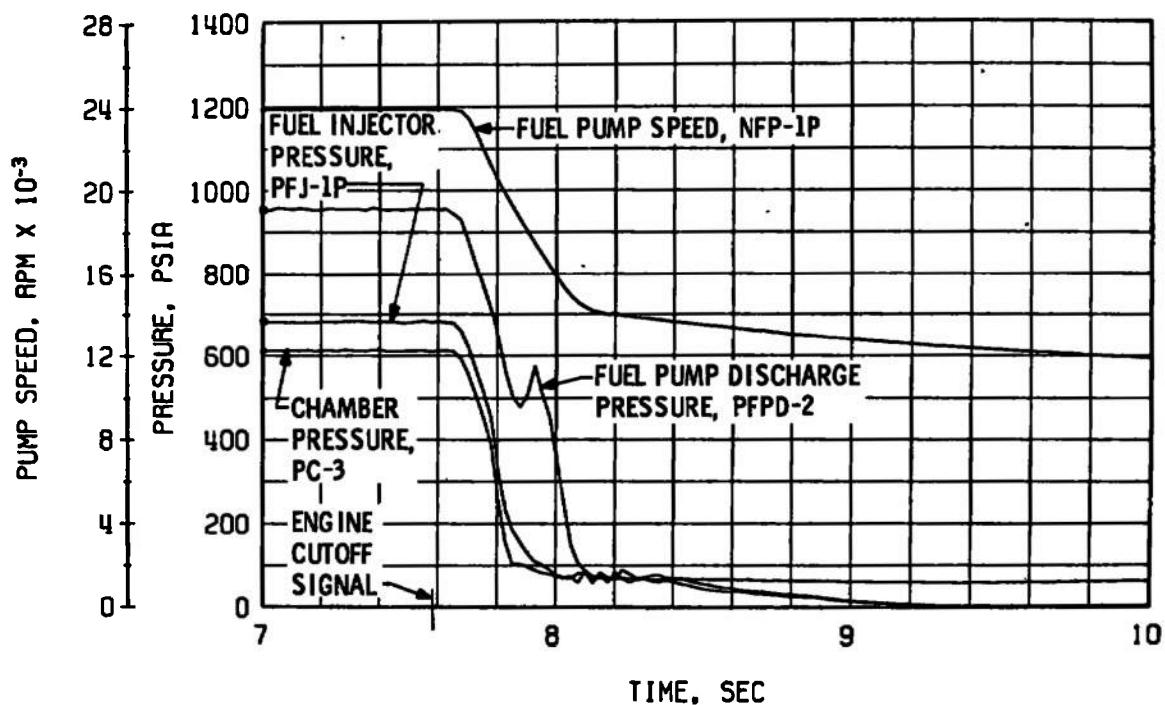
Fig. 41 Thermal Conditioning History of Engine Components, Firing 08D



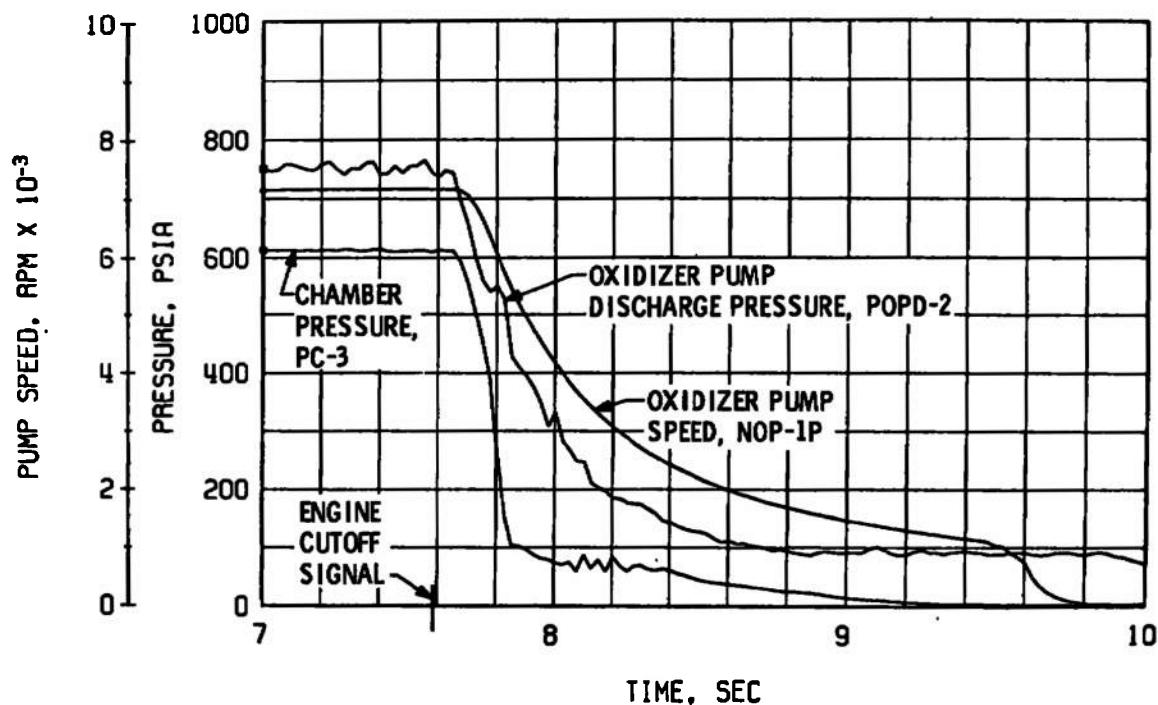
a. Thrust Chamber Fuel System, Start



b. Thrust Chamber Oxidizer System, Start  
 Fig. 42 Engine Transient Operation, Firing 08D



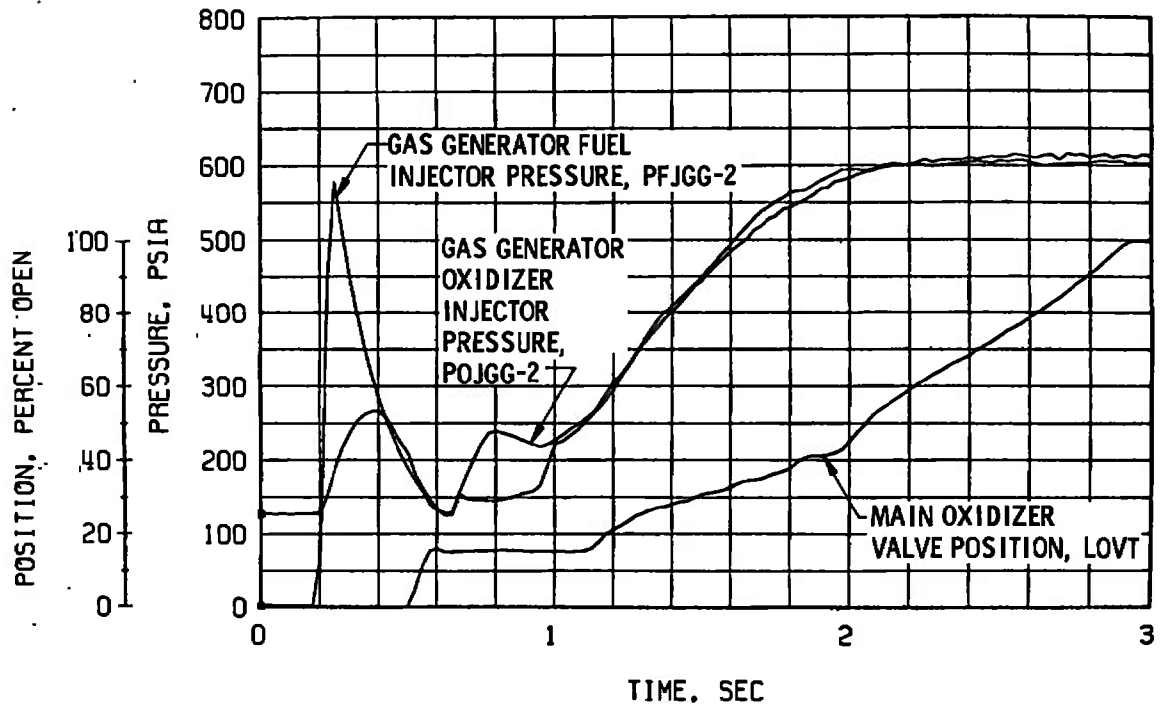
c. Thrust Chamber Fuel System, Shutdown



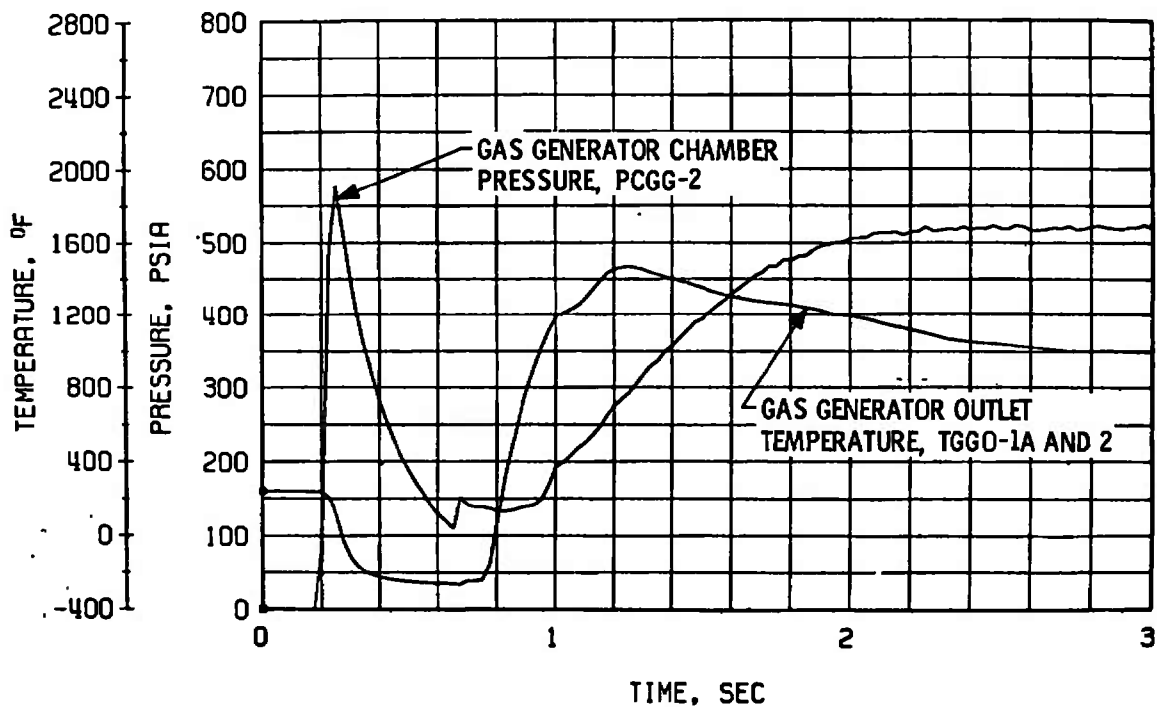
d. Thrust Chamber Oxidizer System, Shutdown

Fig. 42 Continued





e. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start



f. Gas Generator Chamber Pressure and Temperature, Start  
Fig. 42 Continued

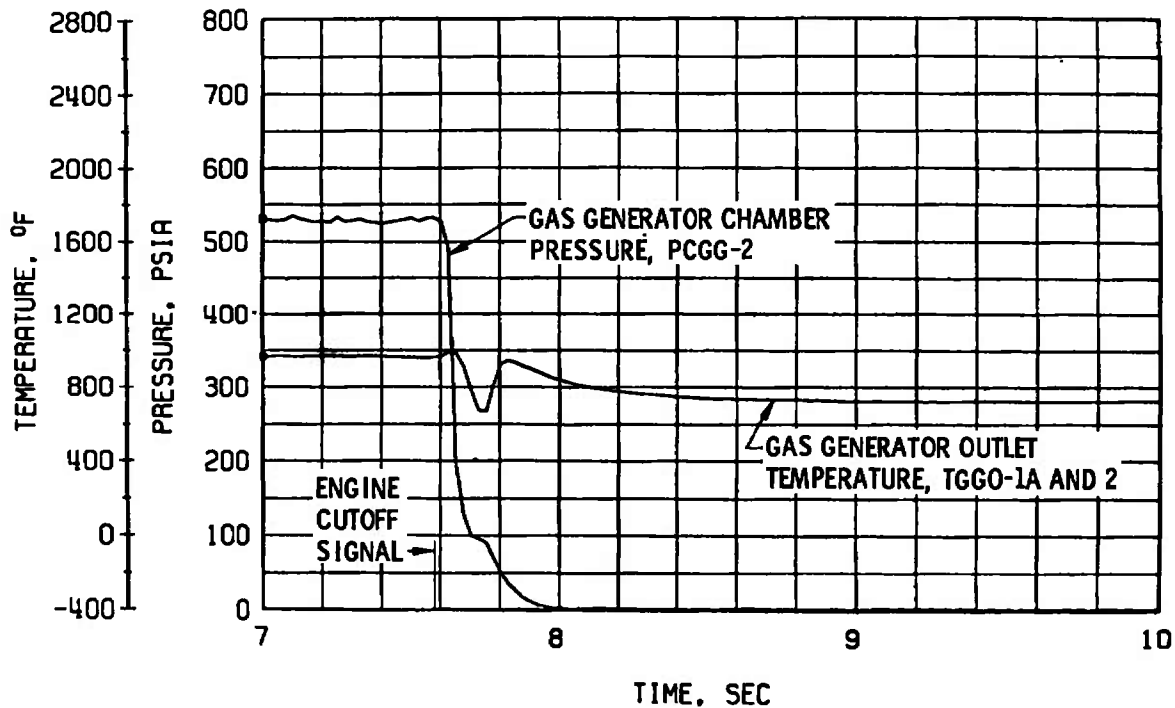
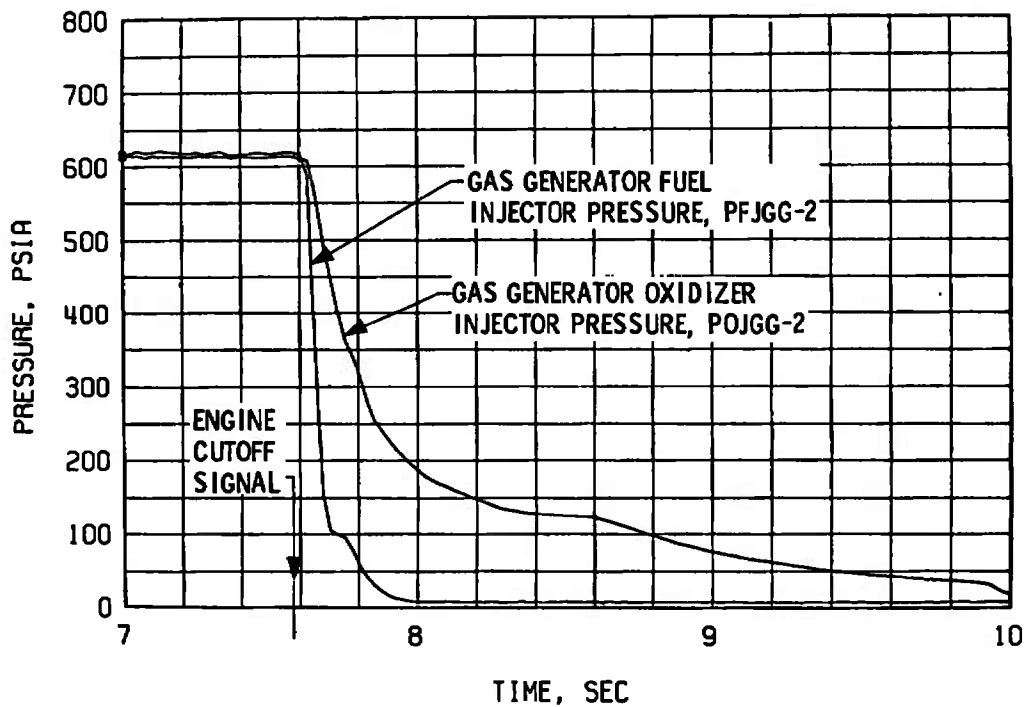


Fig. 42 Concluded

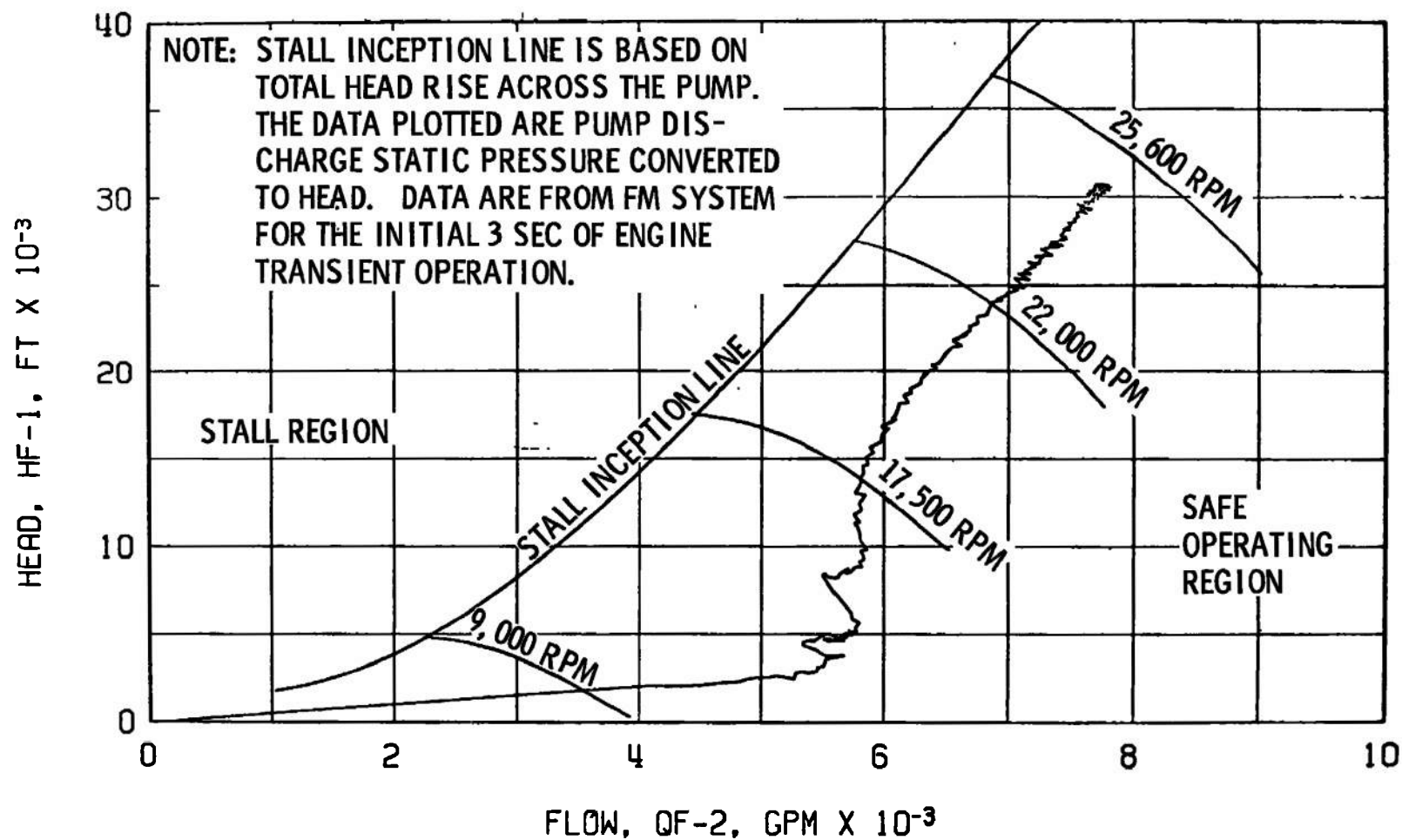


Fig. 43 Fuel Pump Start Transient Performance, Firing 08D

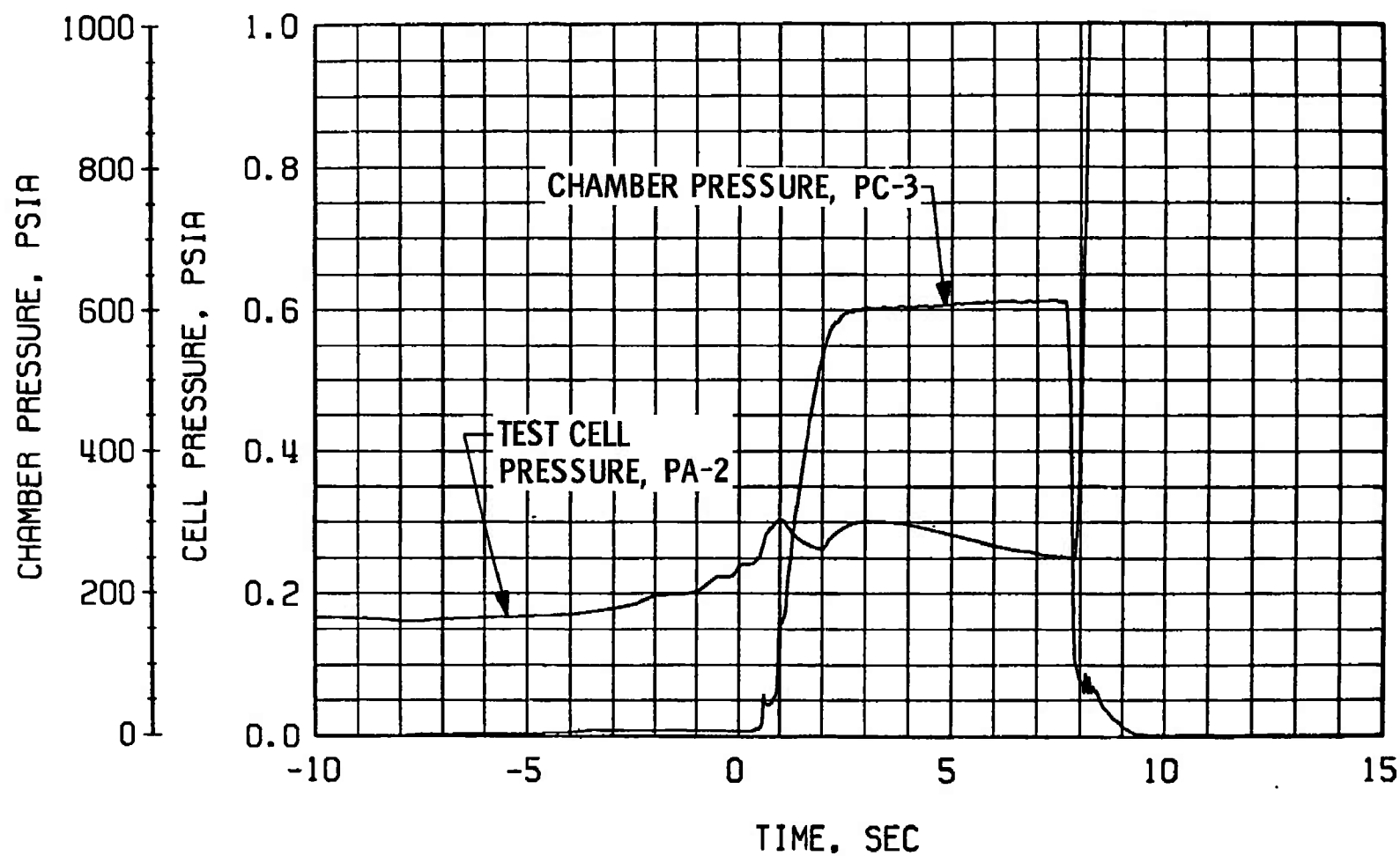
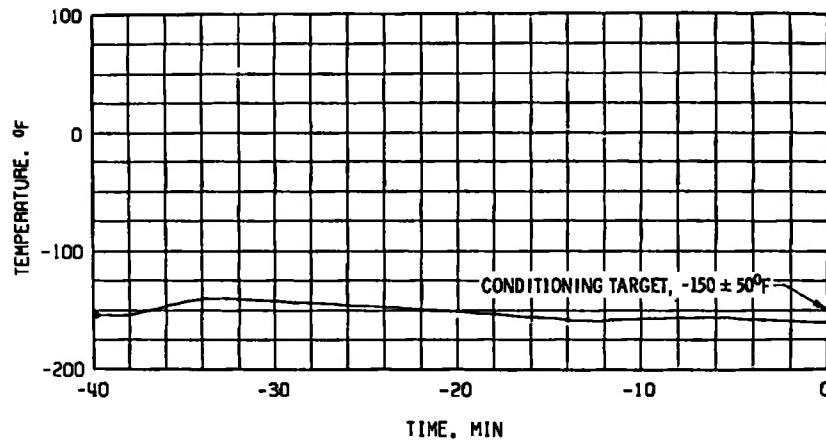
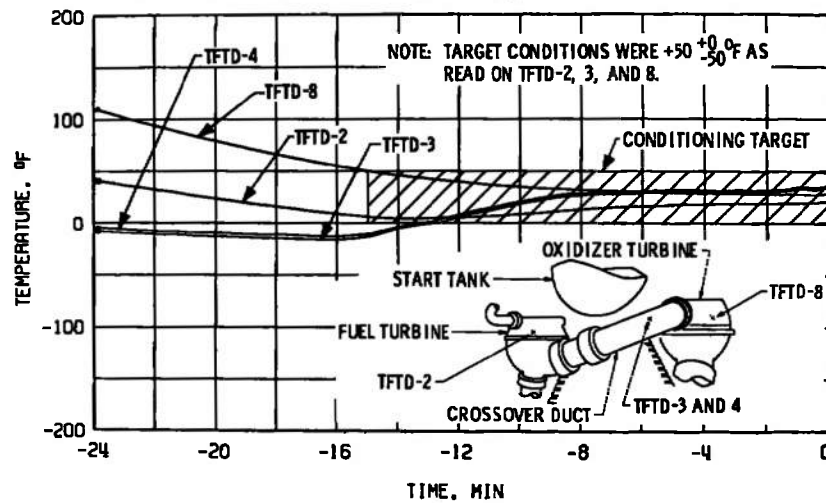


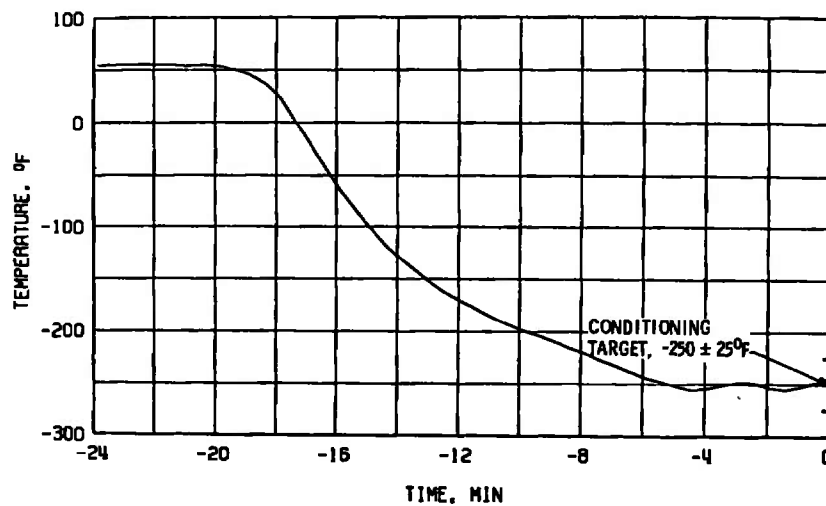
Fig. 44 Engine Ambient and Combustion Chamber Pressure, Firing 08D



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

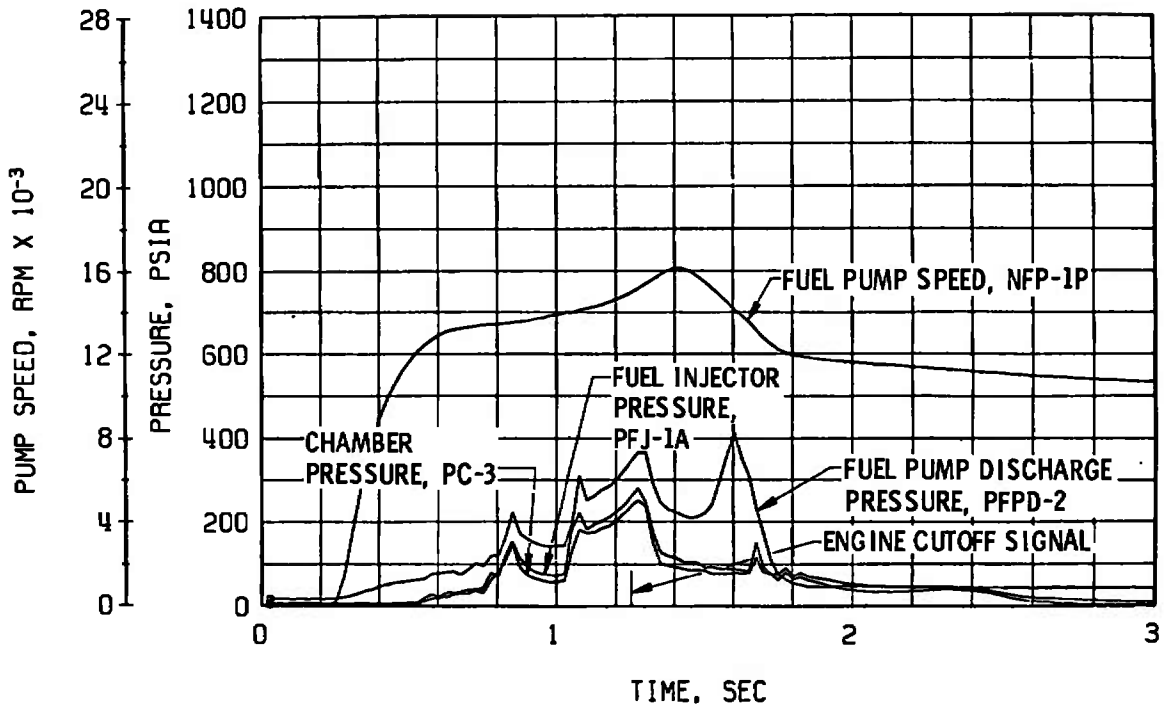


b. Crossover Duct, TFTD

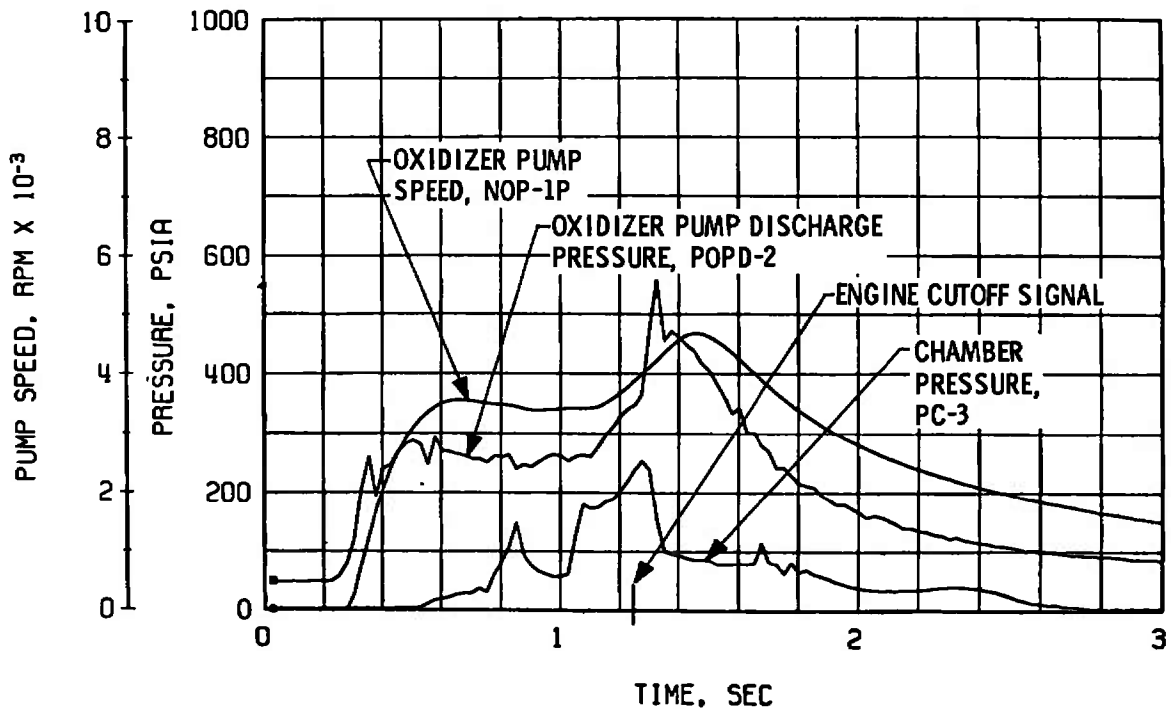


c. Thrust Chamber TTC-1P

Fig. 45 Thermal Conditioning History of Engine Components, Firing 08E

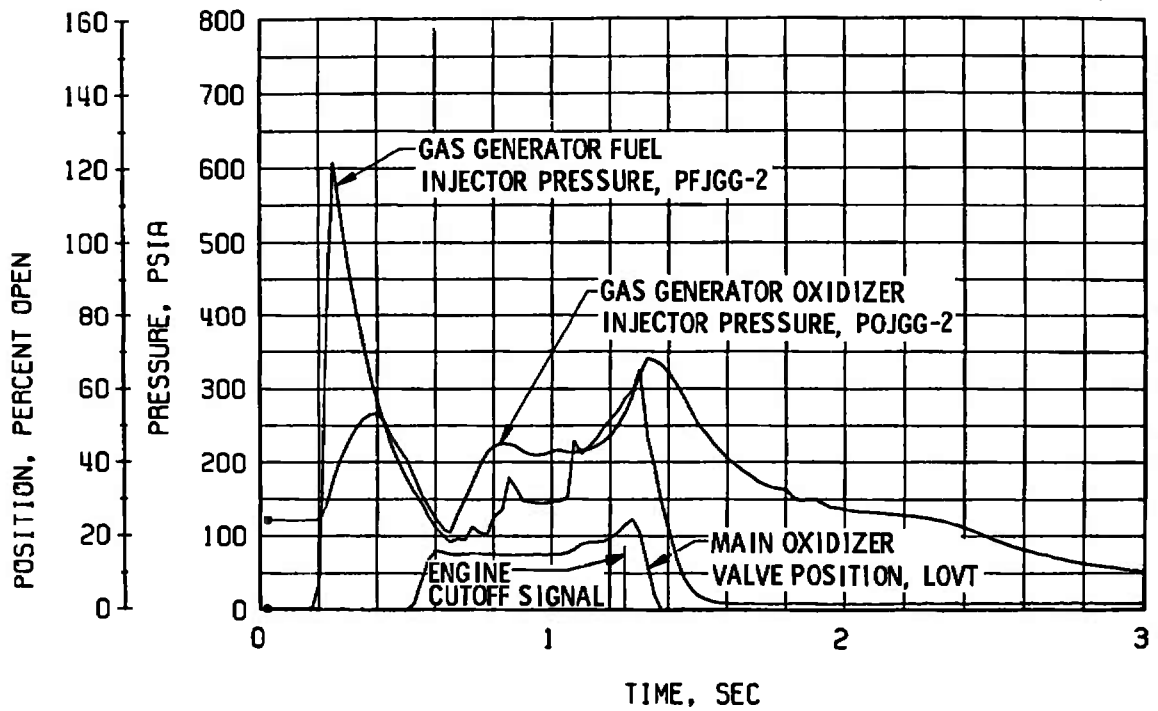


a. Thrust Chamber Fuel System, Start and Shutdown

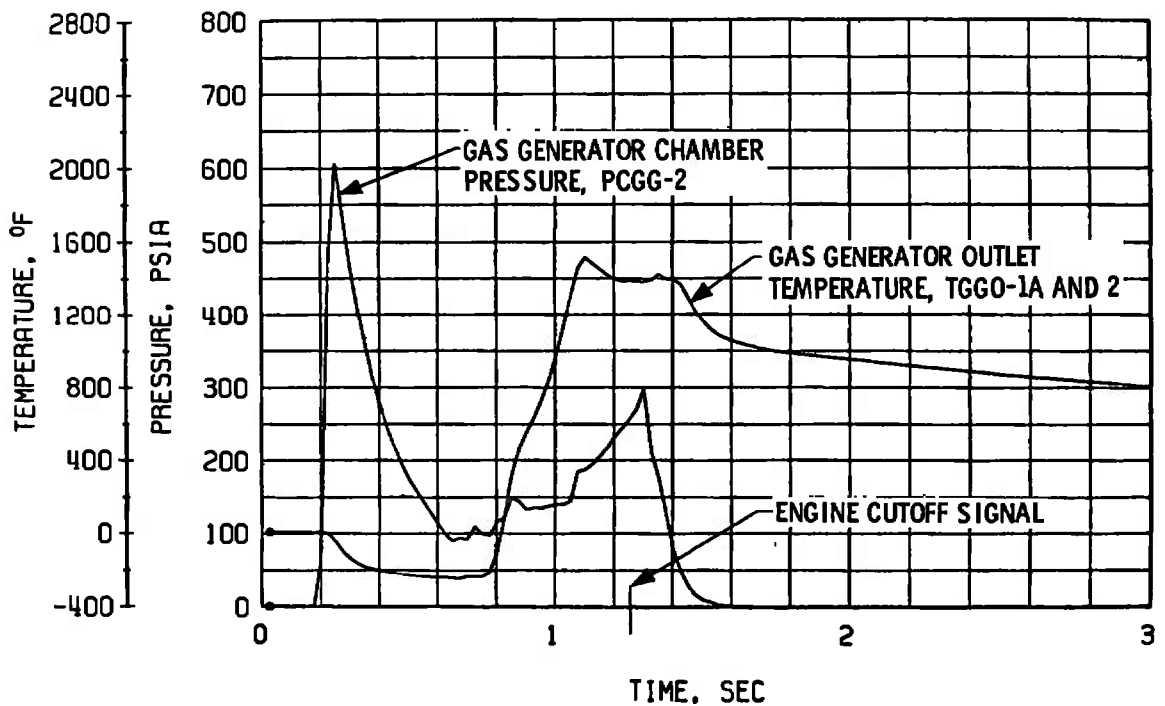


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 46 Engine Transient Operation, Firing 08E



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 46 Concluded

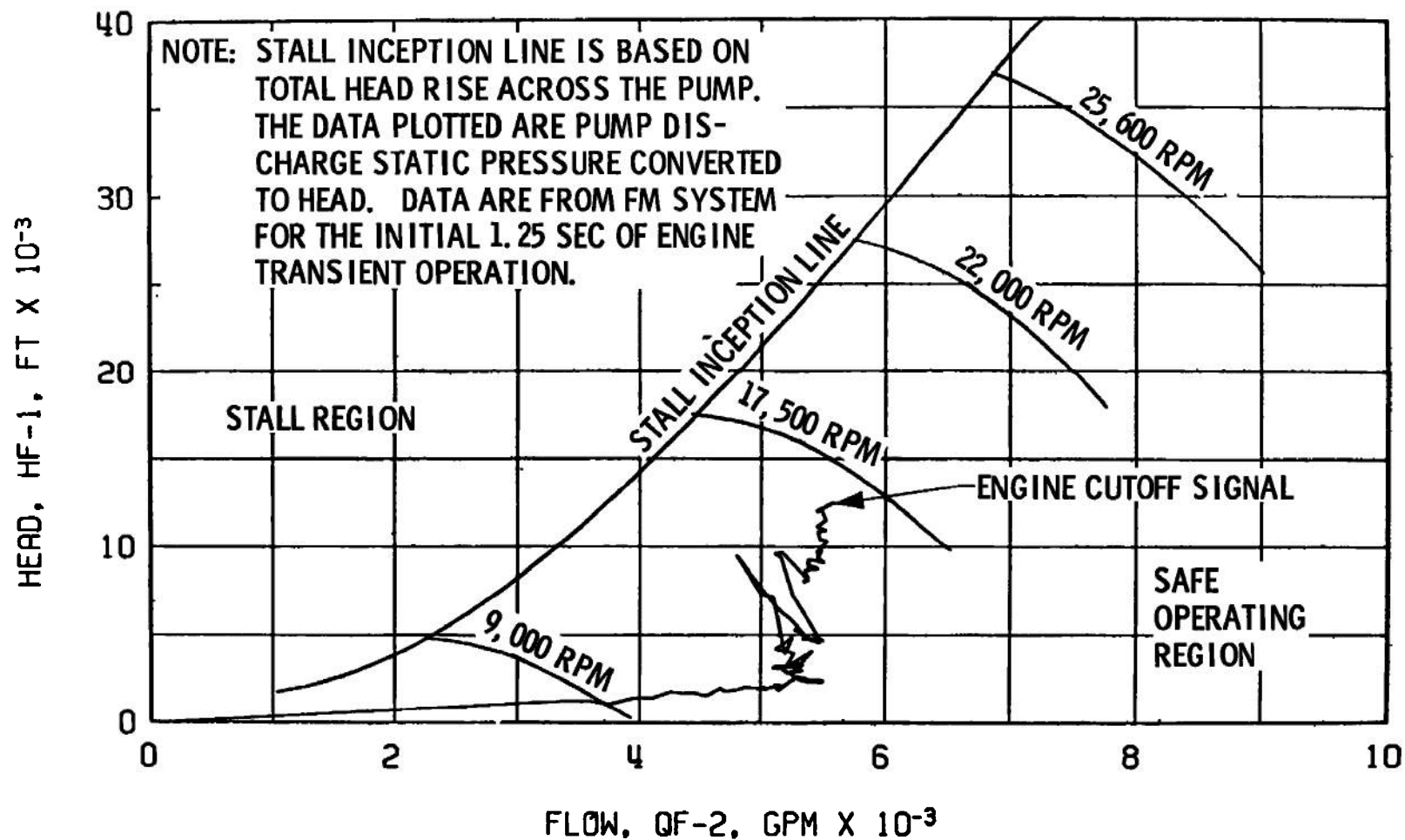


Fig. 47 Fuel Pump Start Transient Performance, Firing 08E



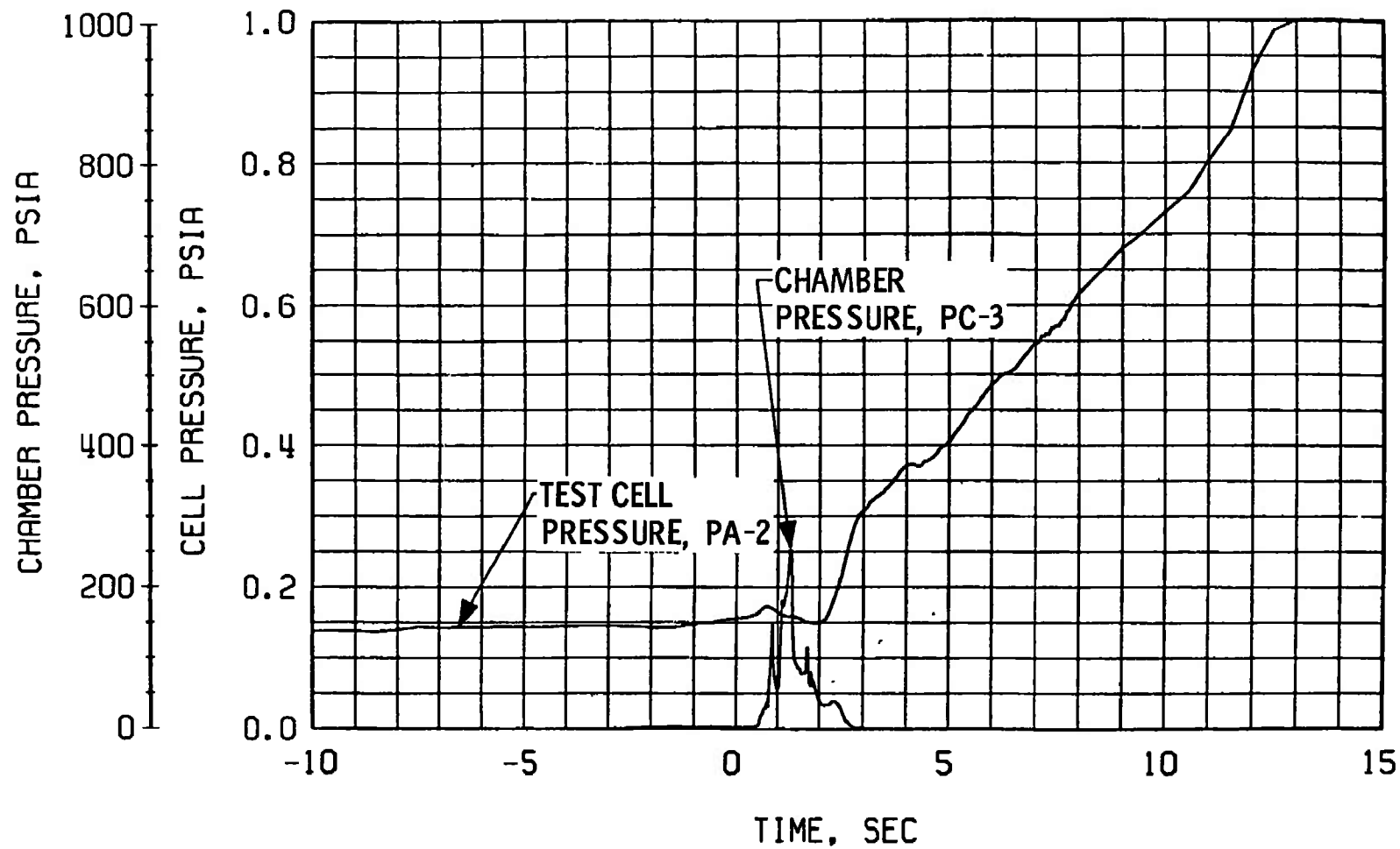


Fig. 48 Engine Ambient and Combustion Chamber Pressure, Firing 0bL

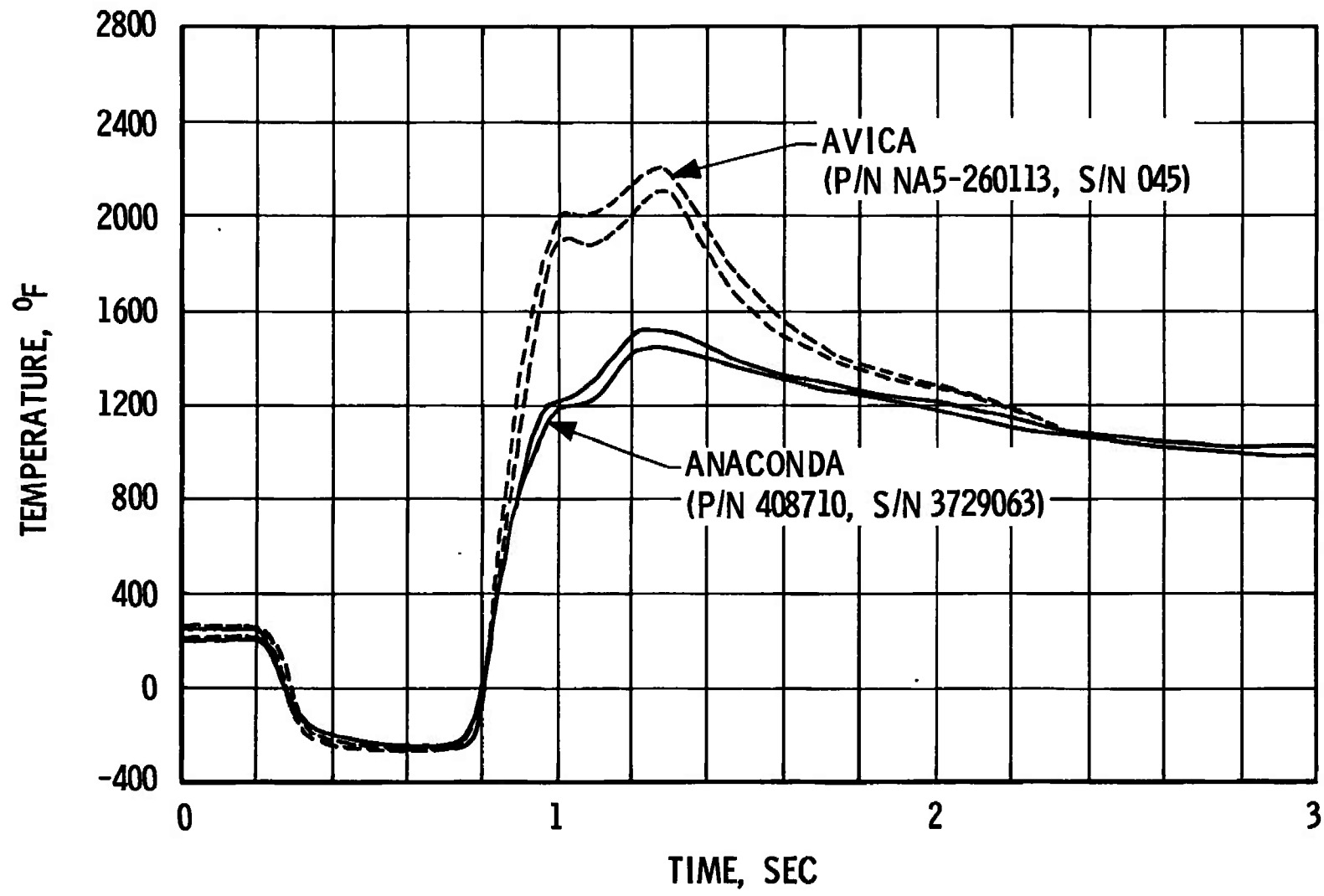


Fig. 49 Transient Gas Generator Temperature Envelopes for the Anaconda and Avica Gas Generator Oxidizer Supply Line Assemblies

**TABLE I**  
**MAJOR ENGINE COMPONENTS**

| Part Name   | P/N         | S/N         |
|---|-------------|-------------|
| Augmented Spark Igniter Assembly                    | 309360-91   | 4071414     |
| Augmented Spark Igniter Oxidizer Valve              | 308880      | 4079065     |
| Auxiliary Flight Instrumentation Package            | 704090-21   | 4075163     |
| Electrical Control Package                          | 502670-51   | 4081748     |
| Fuel Bleed Valve                                    | 309034      | 4084042     |
| Fuel Flowmeter                                      | 251225      | 4074110     |
| Fuel Injector Temperature Transducer                | NA5-27441   | AA013283F66 |
| Fuel Turbopump Assembly                             | 460390-181  | 4073647     |
| Gas Generator Control Valve                         | 309040-31   | 4078292     |
| Gas Generator Fuel Injector and Combustor Assembly  | 308360-11   | 4090408     |
| Gas Generator Oxidizer Injector and Poppet Assembly | 303323      | 4092975     |
| Helium Control Valve                                | NA5-27273   | 372452      |
| Helium Regulator Assembly                           | 558130-111  | 4061139     |
| Helium Tank Vent Control Valve                      | NA5-27273   | 379313      |
| Ignition Phase Control Valve                        | 558069      | 8313398     |
| Main Fuel Valve                                     | 409920      | 4074288     |
| Main Oxidizer Valve                                 | 411031-21   | 4072666     |
| Main-Stage Control Valve                            | 558069      | 8284312     |
| Oxidizer Bleed Valve                                | 309029      | 4076750     |
| Oxidizer Flowmeter                                  | 251216      | 4075154     |
| Oxidizer Turbine Bypass Valve                       | 409940      | 4073096     |
| Oxidizer Turbopump Assembly                         | 458175-111  | 6610105     |
| Pressure-Actuated Purge Control Valve               | 558126      | 4073862     |
| Pressure-Actuated Shutdown Valve Assembly           | 558127-11   | 4074549     |
| Primary Flight Instrumentation Package              | 704095-21   | 4074730     |
| Propellant Utilization Valve                        | 251351-51   | 4075182     |
| Restartable Ignition Detect Probe                   | NA5-27298T2 | 203         |
| Start Tank  | 307579      | 0098        |
| Start Tank Discharge Valve                          | 304386      | 4086957     |
| Start Tank Fill/Refill Valve                        | 557998      | 4091617     |
| Start Tank Vent and Relief Valve                    | 557848      | 4080517     |
| Thrust Chamber Body                                 | 15-205875   | 4062445     |
| Thrust Chamber Injector Assembly                    | XEOR-933703 | 4089721     |

**TABLE II**  
**SUMMARY OF ENGINE ORIFICES**

| Orifice Name  | Part Number | Diameter  | Date Effective  | Comments                                   |
|---|-------------|-----------|-----------------|--|
| Gas Generator Fuel Supply Line  | RD251-4107  | 0.488 in. | July 15, 1968   | Per RFD AEDC-38-68                         |
| Gas Generator Oxidizer Supply Line  | RD251-4106  | 0.284 in. | July 15, 1968   | Per RFD AEDC-38-68                         |
| Gas Generator Control Valve-Opening Control at Main Oxidizer Valve Sequence Outlet Port | RD251-4115  | 0.045 in. | August 16, 1968 |  |
| Oxidizer Turbine Bypass Valve Nozzle  | RD273-8002  | 1.520 in. | July 15, 1968   | Per RFD AEDC-38-68                         |
| Main Oxidizer Valve Closing Control Line  | 410437      | 8.40 scfm | August 16, 1968 | Thermostatic Orifice<br>Per RFD AEDC-12-68 |
| Oxidizer Turbine Exhaust Manifold   | RD251-9004  | 10.00 in. | ①               |  |
| Augmented Spark Igniter Oxidizer Supply Line  | 309358      | 0.125 in. | June 9, 1968    | Per RFD AEDC-24-68                         |
| Augmented Spark Igniter Fuel Supply Line  | 309355      | 0.302 in. | August 1, 1968  | Per RFD AEDC-41-68                         |

①As delivered to AEDC  
RFD - Rocketdyne Field Directive

**TABLE III**  
**ENGINE MODIFICATIONS**

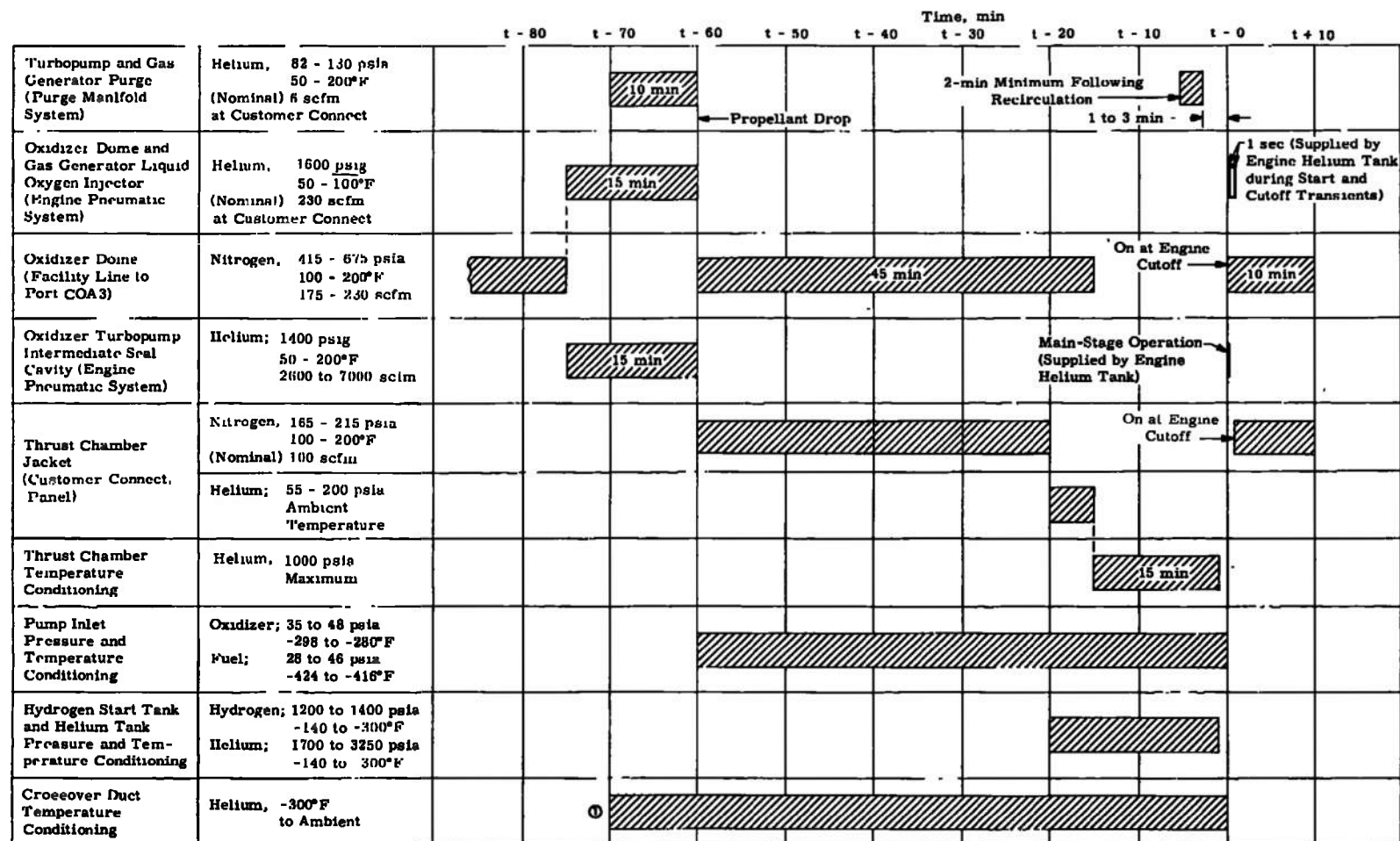
| Modification Number          | Completion Date | Description of Modification  |
|------------------------------|-----------------|--|
| RFD <sup>1</sup> AEDC 45-68  | August 16, 1968 | Insulation of Fuel Supply Line to Augmented Spark Igniter  |
| RFD AEDC 12-68               | August 16, 1968 | Retiming Main Oxidizer Valve to 1700 <sup>+20</sup> <sub>-10</sub> msec  |
| RFD AEDC 42-68               | August 16, 1968 | Retiming Gas Generator Oxidizer Valve Opening Delay to 140 <sup>-5</sup> <sub>-0</sub>   |
| Test J4-1901-07      8/21/68 |                 |  |
| RFD AEDC 45-68               | August 23, 1968 | Deleted Requirements for Referenced RFD (Removed Insulation from Fuel Supply Line to Augmented Spark Igniter)                    |
| RFD AEDC 35-A-67             | August 23, 1968 | Deleted Requirements for Referenced RFD and Installed Seal P/N 408767-3 beneath Ignition Detect Probe of Augmented Spark Igniter |
| Test J4-1901-08      8/27/68 |                 |  |

<sup>1</sup>RFD-Rocketdyne Field Directive

**TABLE IV**  
**ENGINE COMPONENT REPLACEMENTS**

| Replacement                  | Completion Date | Component Replaced  |
|------------------------------|-----------------|---|
| P/N 408710<br>S/N 3729063    | August 16, 1968 | Gas Generator Oxidizer Supply Line<br>P/N NA5-260113<br>S/N 045 |
| P/N 309029<br>S/N 4076750    | August 16, 1968 | Oxidizer Bleed Valve<br>P/N 309029<br>S/N 4078081               |
| Test J4-1901-07      8/21/68 |                 |   |
| None                         |                 |   |
| Test J4-1901-08      8/27/68 |                 |   |

**TABLE V**  
**ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE**



① Conditioning Temperature to be Maintained for the Last 15 min of Pre-Fire

**TABLE VI**  
**SUMMARY OF TEST REQUIREMENTS AND RESULTS**

| Firing Number: J4-1901-07   |                                     | A                                |                | B                                |             | C                                |                | D                                |             | E                                |                       |
|---|-------------------------------------|----------------------------------|----------------|----------------------------------|-------------|----------------------------------|----------------|----------------------------------|-------------|----------------------------------|-----------------------|
|   |                                     | Target                           | Actual         | Target                           | Actual      | Target                           | Actual         | Target                           | Actual      | Target                           | Actual                |
| Time of Day, hr/Firing Date   |                                     | 1050                             | 8/21/68        | 1119                             | 8/21/68     | 1541                             | 8/21/68        | 1608                             | 8/21/68     | 1740                             | 8/21/68               |
| Pressure Altitude at Engine Start, ft (Ref. 1)  |                                     | 100,000                          | 92,500         | 100,000                          | 99,000      | 100,000                          | 98,000         | 100,000                          | 99,000      | 100,000                          | 100,500               |
| Firing Duration, sec <sup>①</sup>   |                                     | 32.5                             | 32.573         | 7.5                              | 7.587       | 32.5                             | 32.573         | 7.5                              | 7.586       | 1.25                             | 1.250                 |
| Fuel Pump Inlet Conditions at Engine Start  | Pressure, psia                      | 26.5 <sup>+1</sup> <sub>-0</sub> | 27.0           | 28.5 <sup>+1</sup> <sub>-0</sub> | 28.7        | 28.5 <sup>+1</sup> <sub>-0</sub> | 28.9           | 28.5 <sup>+1</sup> <sub>-0</sub> | 27.0        | 41.0 <sup>+2</sup> <sub>-1</sub> | 41.3                  |
|   | Temperature, °F                     | -421.4 ± 0.4                     | -421.5         | -421.4 ± 0.4                     | -421.0      | -421.4 ± 0.4                     | -421.7         | -421.4 ± 0.4                     | -420.8      | -421.4 ± 0.4                     | -421.4                |
| Oxidizer Pump Inlet   | Pressure, psia                      | 45.0 <sup>+1</sup> <sub>-0</sub> | 45.1           | 45.0 <sup>+1</sup> <sub>-0</sub> | 45.4        | 45.0 <sup>+1</sup> <sub>-0</sub> | 45.6           | 45.0 <sup>+1</sup> <sub>-0</sub> | 45.3        | 33.0 ± 1                         | 32.5                  |
| Conditions at Engine Start  | Temperature, °F                     | -295.0 ± 0.4                     | -295.0         | -295.0 ± 0.4                     | -294.9      | -295.0 ± 0.4                     | -294.6         | -295.0 ± 0.4                     | -294.4      | -249.0 ± 0.4                     | -293.1                |
| Start Tank Conditions at Engine Start   | Pressure, psia                      | 1400 ± 10                        | 1373           | 1300 ± 10                        | 1303        | 1250 ± 10                        | 1235           | 1200 ± 10                        | 1213        | 1250 ± 10                        | 1254                  |
|   | Temperature, °F                     | -200 ± 10                        | -199           | -265 ± 10                        | -289        | -290 ± 10                        | -202           | -260 ± 10                        | -264        | -140 ± 10                        | -144                  |
| Helium Tank Conditions at Engine Start  | Pressure, psia                      | ---                              | 2171           | ---                              | 2184        | ---                              | 2238           | ---                              | 2122        | ---                              | 2201                  |
|   | Temperature, °F                     | ---                              | -198           | ---                              | -261        | ---                              | -193           | ---                              | -258        | ---                              | -142                  |
| Thrust Chamber Temperature Conditions at Engine Start, °F   | Throat                              | -250 ± 25                        | -242           | 50 ± 25                          | +72         | -250 ± 25                        | -240           | 50 ± 25                          | +74         | -275 ± 25                        | -278                  |
|   | Average Engine Start/ <sub>to</sub> | ---                              | -244/-343      | ---                              | +23/-277    | ---                              | -259/-353      | ---                              | +17/-283    | ---                              | -260/-385             |
| Crossover Duct Temperature at Engine Start, °F <sup>②</sup>                                       | TFTD-2                              | 50 <sup>+0</sup> <sub>-50</sub>  | +20            | ---                              | +434        | 50 <sup>+0</sup> <sub>-50</sub>  | +28            | ---                              | +433        | -100 ± 20                        | -118                  |
|   | TFTD-3/4                            | 50 <sup>+0</sup> <sub>-50</sub>  | +34/+35        | 170 <sup>+15</sup> <sub>-0</sub> | +170/+183   | 50 <sup>+0</sup> <sub>-50</sub>  | +44/+46        | 170 <sup>+15</sup> <sub>-0</sub> | +170/+162   | -100 ± 20                        | -107/-103             |
|   | TFTD-6                              | 50 <sup>+0</sup> <sub>-50</sub>  | +26            | ---                              | +432        | 50 <sup>+0</sup> <sub>-50</sub>  | +31            | ---                              | +434        | -100 ± 20                        | -106                  |
| Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F <sup>③</sup>            |                                     | -150 ± 50                        | -128           | -150 ± 50                        | -153        | -150 ± 50                        | -172           | -150 ± 50                        | -183        | -150 ± 50                        | -127                  |
| Fuel Lead Time, sec <sup>④</sup>  |                                     | 3.0                              | 3.021          | 8.0                              | 7.934       | 3.0                              | 3.019          | 8.0                              | 7.935       | 3.0                              | 3.021                 |
| Propellant in Engine Time, min  |                                     | 30                               | 66             | ---                              | 29          | 30                               | 262            | ---                              | 27          | 30                               | 25                    |
| Propellant Recirculation Time, min  |                                     | 10                               | 10             | 10                               | 10          | 10                               | 10             | 10                               | 12.5        | 10                               | 10                    |
| Start Sequence Logic  |                                     | Normal                           | Normal         | Normal                           | Normal      | Normal                           | Normal         | Normal                           | Normal      | Normal                           | Normal                |
| Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F                                | TOBS-1                              | ---                              | +30            | ---                              | +6          | ---                              | +21            | ---                              | +1          | ---                              | +17                   |
|   | TOBS-2                              | ---                              | +44            | ---                              | +4          | ---                              | +24            | ---                              | -5          | ---                              | -20                   |
|   | TOBS-2B                             | ---                              | +46            | ---                              | +43         | ---                              | +42            | ---                              | +38         | ---                              | +43                   |
| Start Tank Discharge Valve Body Temperature at Engine Start, °F                                   |                                     | ---                              | +38            | ---                              | -8          | ---                              | +3             | ---                              | -23         | ---                              | -33                   |
| Vibration Safety Counts Duration, msec, and Occurrence Time, sec, from t <sub>0</sub>             |                                     | ---                              | 50<br>0.972    | ---                              | 4<br>0.940  | ---                              | 35<br>0.967    | ---                              | 7<br>0.950  | ---                              | 43/0.952<br>158/1.170 |
| Gas Generator Outlet Temperature, °F  | Initial Peak                        | ---                              | 1480           | ---                              | 1210        | ---                              | 1480           | ---                              | 1400        | ---                              | 800                   |
|   | Second Peak                         | ---                              | 1250           | ---                              | 1510        | ---                              | ---            | ---                              | 1510        | ---                              | ---                   |
| Thrust Chamber Ignition (P <sub>c</sub> = 100 psia) Time, sec (Ref. t <sub>0</sub> ) <sup>⑤</sup> |                                     | ---                              | 0.962          | ---                              | 0.944       | ---                              | 0.996          | ---                              | 0.958       | ---                              | 0.967                 |
| Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t <sub>0</sub> ) <sup>⑥</sup>        |                                     | ---                              | 0.982          | ---                              | 1.112       | ---                              | 0.983          | ---                              | 1.086       | ---                              | 0.966                 |
| Main-Stage Pressure No. 2, sec (Ref. t <sub>0</sub> ) <sup>⑦</sup>                                |                                     | ---                              | 1.888          | ---                              | 1.876       | ---                              | 1.668          | ---                              | 1.586       | ---                              | ---                   |
| Thrust Chamber Pressure Attains 550 psia, sec (Ref. t <sub>0</sub> )                              |                                     | ---                              | 1.958          | ---                              | 2.050       | ---                              | 1.947          | ---                              | 2.050       | ---                              | ---                   |
| Propellant Utilization Valve Position, Engine Start/t <sub>0</sub> + 10 sec                       |                                     | Null<br>Closed                   | Null<br>Closed | Open<br>---                      | Open<br>--- | Null<br>Closed                   | Null<br>Closed | Open<br>---                      | Open<br>--- | Null<br>---                      | Null<br>---           |

Notes: ①Data reduced from oscillogram.  
②Component conditioning to be maintained within limits for last 15 min before engine start.  
③Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.

TABLE VI (Concluded)

| Firing Number: J4-1901-09  |                            | A                                    |           | B                                  |           | C                                   |          | D                                  |           | E                                  |           |
|--|----------------------------|--------------------------------------|-----------|------------------------------------|-----------|-------------------------------------|----------|------------------------------------|-----------|------------------------------------|-----------|
|  |                            | Target                               | Actual    | Target                             | Actual    | Target                              | Actual   | Target                             | Actual    | Target                             | Actual    |
| Time of Day, hr/Firing Date  |                            | 1045                                 | 8/27/68   | 1114                               | 8/27/68   | 1315                                | 8/27/68  | 1347                               | 8/27/68   | 1443                               | 8/27/68   |
| Pressure Altitude at Engine Start, ft (Ref. 1)   |                            | 100,000                              | 90,000    | 100,000                            | 102,000   | 100,000                             | 100,000  | 100,000                            | 100,000   | 100,000                            | 102,000   |
| Firing Duration, sec <sup>①</sup>  |                            | 32.5                                 | 32.572    | 7.5                                | 7.567     | 32.5                                | 32.572   | 7.5                                | 7.588     | 1.25                               | 1.250     |
| Fuel Pump Inlet Conditions at Engine Start   | Pressure, psia             | 41.0 ± 1                             | 41.3      | 26.5 <sup>+1</sup> / <sub>-0</sub> | 27.3      | 26.5 <sup>+1</sup> / <sub>-0</sub>  | 27.1     | 41.0 ± 1                           | 41.0      | 26.5 <sup>+1</sup> / <sub>-0</sub> | 27.4      |
|  | Temperature, °F            | -420.4 ± 0.4                         | -420.7    | -421.4 ± 0.4                       | -421.3    | -421.4 ± 0.4                        | -421.5   | -421.4 ± 0.4                       | -421.0    | -421.4 ± 0.4                       | -421.0    |
| Oxidizer Pump Inlet Conditions at Engine Start   | Pressure, psia             | 33.0 <sup>+1</sup> / <sub>-0</sub>   | 34.9      | 45.0 <sup>+1</sup> / <sub>-0</sub> | 45.5      | 45.0 <sup>+1</sup> / <sub>-0</sub>  | 45.5     | 45.0 <sup>+1</sup> / <sub>-0</sub> | 45.0      | 45.0 <sup>+1</sup> / <sub>-0</sub> | 45.2      |
|  | Temperature, °F            | -294.5 ± 0.4                         | -294.5    | -295.0 ± 0.4                       | -295.2    | -295.0 ± 0.4                        | -295.3   | -295.0 ± 0.4                       | -294.7    | -295.0 ± 0.4                       | -294.6    |
| Start Tank Conditions at Engine Start  | Pressure, psia             | 1400 ± 10                            | 1374      | 1300 ± 10                          | 1289      | 1400 ± 10                           | 1367     | 1300 ± 10                          | 1298      | 1400 ± 10                          | 1406      |
|  | Temperature, °F            | -140 ± 10                            | -145      | -265 ± 10                          | -269      | -200 ± 10                           | -203     | -265 ± 10                          | -285      | -200 ± 10                          | -204      |
| Helium Tank Conditions at Engine Start   | Pressure, psia             | ---                                  | 2172      | ---                                | 2124      | ---                                 | 2223     | ---                                | 2149      | ---                                | 2104      |
|  | Temperature, °F            | ---                                  | -133      | ---                                | -291      | ---                                 | -199     | ---                                | -267      | ---                                | -200      |
| Thrust Chamber Temperature Conditions at Engine Start, °F                              | Throat                     | -150 <sup>+20</sup> / <sub>-10</sub> | -154      | 50 ± 25                            | +82       | -90 <sup>+20</sup> / <sub>-10</sub> | -83      | 50 ± 25                            | +94       | -250 ± 25                          | -244      |
|  | Average Engine Start $t_0$ | ---                                  | -149/-175 | ---                                | +22/-254  | ---                                 | -93/-195 | ---                                | +29/-338  | ---                                | -264/-359 |
| Crossover Duct Temperature at Engine Start, °F <sup>②</sup>                            | TFTD-2                     | -100 ± 20                            | -107      | ---                                | +388      | 50 <sup>+0</sup> / <sub>-50</sub>   | +7       | ---                                | +422      | 50 <sup>+0</sup> / <sub>-50</sub>  | +21       |
|  | TFTD-3/-4                  | -100 ± 20                            | -84/-81   | 170 <sup>+15</sup> / <sub>-0</sub> | +130/+185 | 50 <sup>+0</sup> / <sub>-50</sub>   | +25/+26  | 170 <sup>+15</sup> / <sub>-0</sub> | +175/+183 | 50 <sup>+0</sup> / <sub>-50</sub>  | +35/+35   |
|  | TFTD-8                     | -100 ± 20                            | -90       | ---                                | +419      | 50 <sup>+0</sup> / <sub>-50</sub>   | +21      | ---                                | +431      | 50 <sup>+0</sup> / <sub>-50</sub>  | +28       |
| Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F <sup>③</sup> |                            | -100 ± 50                            | -82       | -150 ± 50                          | -141      | -150 ± 50                           | -177     | -150 ± 50                          | -169      | -150 ± 50                          | -190      |
| Fuel Lead Time, sec <sup>④</sup>   |                            | 1.0                                  | 1.000     | 8.0                                | 7.934     | 3.0                                 | 3.021    | 8.0                                | 7.931     | 3.0                                | 3.017     |
| Propellant in Engine Time, min   |                            | 30                                   | 64        | ---                                | 28        | 30                                  | 121      | ---                                | 31        | 30                                 | 31        |
| Propellant Recirculation Time, min   |                            | 10                                   | 10        | 10                                 | 11.5      | 10                                  | 10       | 10                                 | 14        | 10                                 | 10        |
| Start Sequence Logic   |                            | Normal                               | Normal    | Normal                             | Normal    | Normal                              | Normal   | Normal                             | Normal    | Normal                             | Normal    |
| Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F                     | TOBS-1                     | ---                                  | +28       | ---                                | +8        | ---                                 | +12      | ---                                | -1        | ---                                | +19       |
|  | TOBS-2                     | ---                                  | +28       | ---                                | 0         | ---                                 | -4       | ---                                | -6        | ---                                | +6        |
|  | TOBS-2B                    | ---                                  | +40       | ---                                | +32       | ---                                 | +34      | ---                                | +28       | ---                                | +38       |
| Start Tank Discharge Valve Body Temperature at Engine Start, °F                        |                            | 50 ± 25                              | +62       | ---                                | +7        | ---                                 | -40      | ---                                | -49       | ---                                | +34       |
| Vibration Safety Counts Duration, msec, and Occurrence Time, sec, from $t_0$           |                            | ---                                  | 18        | ---                                | 5         | ---                                 | 24       | ---                                | 241       | ---                                | 46/0.798  |
|  |                            | ---                                  | 0.995     | ---                                | 0.950     | ---                                 | 0.862    | ---                                | 0.589     | ---                                | 36/1.034  |
| Gas Generator Outlet Temperature, °F   | Initial Peak               | ---                                  | 930       | ---                                | 1210      | ---                                 | 1380     | ---                                | 1200      | ---                                | 1520      |
|  | Second Peak                | ---                                  | ---       | ---                                | 1460      | ---                                 | 1420     | ---                                | 1460      | ---                                | ---       |
| Thrust Chamber Ignition ( $P_c = 100$ psia) Time, sec (Ref. $t_0$ ) <sup>⑤</sup>       |                            | ---                                  | 0.997     | ---                                | 0.949     | ---                                 | 0.982    | ---                                | 0.962     | ---                                | 0.903     |
| Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. $t_0$ ) <sup>⑥</sup>      |                            | ---                                  | 0.975     | ---                                | 1.093     | ---                                 | 0.989    | ---                                | 1.097     | ---                                | 1.037     |
| Main-Stage Pressure No. 2, sec (Ref. $t_0$ ) <sup>⑦</sup>                              |                            | ---                                  | 1.714     | ---                                | 1.888     | ---                                 | 1.598    | ---                                | 1.679     | ---                                | ---       |
| Time Chamber Pressure Attains 550 psia, sec (Ref. $t_0$ )                              |                            | ---                                  | 1.875     | ---                                | 2.060     | ---                                 | 1.850    | ---                                | 2.033     | ---                                | ---       |
| Propellant Utilization Valve Position, Engine Start/ $t_0$ + 10 sec                    |                            | Null                                 | Closed    | Null                               | Closed    | Open                                | ---      | Open                               | ---       | Null                               | ---       |

Notes: ① Data reduced from oscillogram.

② Component conditioning to be maintained within limits for last 15 min before engine start.

③ Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, which is longer.



**TABLE VII  
ENGINE VALVE TIMINGS**

| Firing<br>Number<br>J4-1901-07 | Start                           |                                |                                  |                                 |                                |                                  |                                 |                                |                                  |                                    |                                |                                  |                                     |                                |                                  |                                 |                                |                                  |                                  |                                |                                  |                                  |                                |                                  |
|--------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|------------------------------------|--------------------------------|----------------------------------|-------------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|
|                                | Start Tank Discharge Valve      |                                |                                  |                                 |                                |                                  | Main Fuel Valve                 |                                |                                  | Main Oxidizer Valve<br>First Stage |                                |                                  | Main Oxidizer Valve<br>Second Stage |                                |                                  | Gas Generator<br>Fuel Poppet    |                                |                                  | Gas Generator<br>Oxidizer Poppet |                                |                                  | Oxidizer Turbine<br>Bypass Valve |                                |                                  |
|                                | Time<br>of<br>Opening<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal    | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal     | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal  | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal  | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec |
| A                              | 0.0                             | 0.127                          | 0.115                            | 0.450                           | 0.124                          | 0.248                            | -3.021                          | 0.093                          | 0.097                            | 0.450                              | 0.053                          | 0.050                            | 0.450                               | 0.532                          | 1.874                            | 0.450                           | 0.104                          | 0.033                            | 0.450                            | 0.178                          | 0.083                            | 0.450                            | 0.217                          | 0.278                            |
| B                              | 0.0                             | 0.132                          | 0.121                            | 0.450                           | 0.131                          | 0.248                            | -7.934                          | 0.079                          | 0.114                            | 0.450                              | 0.055                          | 0.052                            | 0.450                               | 0.662                          | 1.773                            | 0.450                           | 0.112                          | 0.034                            | 0.450                            | 0.194                          | 0.091                            | 0.450                            | 0.212                          | 0.287                            |
| C                              | 0.0                             | 0.128                          | 0.112                            | 0.448                           | 0.129                          | 0.251                            | -3.019                          | 0.082                          | 0.107                            | 0.448                              | 0.058                          | 0.053                            | 0.448                               | 0.545                          | 1.883                            | 0.448                           | 0.109                          | 0.031                            | 0.448                            | 0.186                          | 0.084                            | 0.448                            | 0.218                          | 0.283                            |
| D                              | 0.0                             | 0.132                          | 0.117                            | 0.449                           | 0.134                          | 0.249                            | -7.935                          | 0.079                          | 0.122                            | 0.449                              | 0.055                          | 0.058                            | 0.449                               | 0.639                          | 1.788                            | 0.449                           | 0.112                          | 0.032                            | 0.449                            | 0.194                          | 0.095                            | 0.449                            | 0.214                          | 0.279                            |
| E                              | 0.0                             | 0.134                          | 0.116                            | 0.450                           | 0.134                          | 0.281                            | -3.021                          | 0.073                          | 0.108                            | 0.450                              | 0.054                          | 0.057                            | 0.450                               | 0.536                          | ---                              | 0.450                           | 0.108                          | 0.036                            | 0.450                            | 0.193                          | 0.110                            | 0.450                            | 0.218                          | 0.287                            |
| Final<br>Sequence              | 0.0                             | 0.091                          | 0.089                            | 0.450                           | 0.131                          | 0.236                            | -0.998                          | 0.059                          | 0.102                            | 0.450                              | 0.054                          | 0.042                            | 0.450                               | 0.602                          | 1.880                            | 0.450                           | 0.088                          | 0.032                            | 0.450                            | 0.143                          | 0.073                            | 0.450                            | 0.202                          | 0.278                            |

| Firing<br>Number<br>J4-1901-07 | Shutdown                        |                                |                                  |                                 |                                |                                  |                                 |                                |                                  |                                  |                                |                                  |                                  |                                |                                  |
|--------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|
|                                | Main Fuel Valve                 |                                |                                  | Main Oxidizer Valve             |                                |                                  | Gas Generator<br>Fuel Poppet    |                                |                                  | Gas Generator<br>Oxidizer Poppet |                                |                                  | Oxidizer Turbine<br>Bypass Valve |                                |                                  |
|                                | Time<br>of<br>Closing<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal  | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal  | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec |
| A                              | 32.573                          | 0.108                          | 0.323                            | 32.573                          | 0.087                          | 0.174                            | 32.573                          | 0.067                          | 0.020                            | 32.573                           | 0.030                          | 0.016                            | 32.573                           | 0.256                          | 0.536                            |
| B                              | 7.593                           | 0.099                          | 0.315                            | 7.593                           | 0.074                          | 0.184                            | 7.583                           | 0.074                          | 0.016                            | 7.593                            | 0.035                          | 0.014                            | 7.593                            | 0.227                          | 0.494                            |
| C                              | 32.573                          | 0.113                          | 0.348                            | 32.573                          | 0.089                          | 0.190                            | 32.573                          | 0.074                          | 0.023                            | 32.573                           | 0.033                          | 0.014                            | 32.573                           | 0.252                          | 0.521                            |
| D                              | 7.588                           | 0.101                          | 0.329                            | 7.588                           | 0.076                          | 0.179                            | 7.588                           | 0.076                          | 0.016                            | 7.588                            | 0.034                          | 0.013                            | 7.588                            | 0.226                          | 0.488                            |
| E                              | 1.250                           | 0.097                          | 0.291                            | 1.250                           | ---                            | ---                              | 1.250                           | 0.089                          | 0.026                            | 1.250                            | 0.049                          | 0.021                            | 1.250                            | 0.164                          | 0.574                            |
| Final<br>Sequence              | 6.174                           | 0.076                          | 0.224                            | 8.174                           | 0.061                          | 0.122                            | 6.174                           | 0.094                          | 0.038                            | 8.174                            | 0.059                          | 0.028                            | 6.174                            | 0.222                          | 0.581                            |

- Notes:
1. All valve signal times are referenced to  $t_0$ .
  2. Valve delay time is the time required for initial valve movement after the valve "open" or "closed" solenoid has been energized.
  3. Final sequence check is conducted without propellants and within 12 hr before testing.
  4. Data reduced from oscillogram.

TABLE VII (Concluded)

| Firing<br>Number<br>J4-1901-08 | Start                           |                                |                                  |                                 |                                |                                  |                                 |                                |                                  |                                    |                                |                                  |                                     |                                |                                  |                                 |                                |                                  |                                  |                                |                                  |                                  |                                |                                  |
|--------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|------------------------------------|--------------------------------|----------------------------------|-------------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|
|                                | Start Tank Discharge Valve      |                                |                                  |                                 |                                |                                  | Main Fuel Valve                 |                                |                                  | Main Oxidizer Valve<br>First Stage |                                |                                  | Main Oxidizer Valve<br>Second Stage |                                |                                  | Gas Generator<br>Fuel Poppet    |                                |                                  | Gas Generator<br>Oxidizer Poppet |                                |                                  | Oxidizer Turbine<br>Bypass Valve |                                |                                  |
|                                | Time<br>of<br>Opening<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal    | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal     | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal  | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal  | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec |
| A                              | 0.0                             | 0.123                          | 0.112                            | 0.450                           | 0.125                          | 0.243                            | -1.000                          | 0.081                          | 0.107                            | 0.450                              | 0.054                          | 0.048                            | 0.450                               | 0.525                          | 1.810                            | 0.450                           | 0.104                          | 0.031                            | 0.450                            | 0.184                          | 0.081                            | 0.450                            | 0.223                          | 0.281                            |
| B                              | 0.0                             | 0.129                          | 0.117                            | 0.449                           | 0.125                          | 0.250                            | -7.934                          | 0.078                          | 0.114                            | 0.449                              | 0.055                          | 0.049                            | 0.449                               | 0.644                          | 1.791                            | 0.449                           | 0.108                          | 0.032                            | 0.449                            | 0.183                          | 0.092                            | 0.449                            | 0.218                          | 0.284                            |
| C                              | 0.0                             | 0.135                          | 0.126                            | 0.448                           | 0.130                          | 0.266                            | -3.021                          | 0.082                          | 0.114                            | 0.448                              | 0.056                          | 0.054                            | 0.448                               | 0.541                          | 1.924                            | 0.448                           | 0.109                          | 0.032                            | 0.448                            | 0.188                          | 0.092                            | 0.448                            | 0.219                          | 0.286                            |
| D                              | 0.0                             | 0.138                          | 0.123                            | 0.450                           | 0.138                          | 0.254                            | -7.831                          | 0.079                          | 0.124                            | 0.450                              | 0.056                          | 0.054                            | 0.450                               | 0.647                          | 1.808                            | 0.450                           | 0.111                          | 0.031                            | 0.450                            | 0.186                          | 0.081                            | 0.450                            | 0.216                          | 0.287                            |
| E                              | 0.0                             | 0.127                          | 0.113                            | 0.448                           | 0.123                          | 0.245                            | -3.017                          | 0.086                          | 0.109                            | 0.448                              | 0.053                          | 0.051                            | 0.448                               | 0.589                          | ---                              | 0.448                           | 0.105                          | 0.031                            | 0.448                            | 0.187                          | 0.086                            | 0.448                            | 0.205                          | 0.279                            |
| Final<br>Sequence              | 0.0                             | 0.089                          | 0.093                            | 0.450                           | 0.128                          | 0.241                            | -0.997                          | 0.053                          | 0.111                            | 0.450                              | 0.050                          | 0.047                            | 0.450                               | 0.597                          | 1.688                            | 0.450                           | 0.085                          | 0.037                            | 0.450                            | 0.142                          | 0.074                            | 0.450                            | 0.204                          | 0.273                            |

| Firing<br>Number<br>J4-1801-08 | Shutdown                        |                                |                                  |                                 |                                |                                  |                                 |                                |                                  |                                  |                                |                                  |                                  |                                |                                  |
|--------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|
|                                | Main Fuel Valve                 |                                |                                  | Main Oxidizer Valve             |                                |                                  | Gas Generator<br>Fuel Poppet    |                                |                                  | Gas Generator<br>Oxidizer Poppet |                                |                                  | Oxidizer Turbine<br>Bypass Valve |                                |                                  |
|                                | Time<br>of<br>Closing<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal  | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal  | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec |
| A                              | 32.572                          | 0.104                          | 0.298                            | 32.572                          | 0.080                          | 0.167                            | 32.572                          | 0.064                          | 0.022                            | 32.572                           | 0.029                          | 0.013                            | 32.572                           | 0.257                          | 0.576                            |
| B                              | 7.587                           | 0.101                          | 0.314                            | 7.587                           | 0.079                          | 0.173                            | 7.587                           | 0.074                          | 0.023                            | 7.587                            | 0.034                          | 0.016                            | 7.587                            | 0.233                          | 0.527                            |
| C                              | 32.572                          | 0.113                          | 0.352                            | 32.572                          | 0.085                          | 0.182                            | 32.572                          | 0.069                          | 0.020                            | 32.572                           | 0.030                          | 0.014                            | 32.572                           | 0.244                          | 0.529                            |
| D                              | 7.588                           | 0.109                          | 0.336                            | 7.588                           | 0.083                          | 0.178                            | 7.588                           | 0.076                          | 0.026                            | 7.588                            | 0.036                          | 0.014                            | 7.588                            | 0.226                          | 0.487                            |
| E                              | 1.250                           | 0.101                          | 0.317                            | 1.250                           | ---                            | ---                              | 1.250                           | 0.081                          | 0.023                            | 1.250                            | 0.043                          | 0.018                            | 1.250                            | 0.158                          | 0.529                            |
| Final<br>Sequence              | 6.188                           | 0.077                          | 0.228                            | 6.169                           | 0.064                          | 0.121                            | 6.168                           | 0.095                          | 0.039                            | 6.169                            | 0.061                          | 0.025                            | 6.169                            | 0.226                          | 0.592                            |

- Notes:
1. All valve signal times are referenced to  $t_0$ .
  2. Valve delay time is the time required for initial valve movement after the valve "open" or "closed" solenoid has been energized.
  3. Final sequence check is conducted without propellants and within 12 hr before testing.
  4. Data reduced from oscillogram.

**TABLE VIII  
ENGINE PERFORMANCE SUMMARY**

| Firing Number J4-1901-               |  | 07A     |            | 07C     |            | 08A     |            | 08C     |            |
|--------------------------------------|--|---------|------------|---------|------------|---------|------------|---------|------------|
|                                      |  | Site    | Normalized | Site    | Normalized | Site    | Normalized | Site    | Normalized |
| Overall<br>Engine<br>Performance     | Thrust, lbf                                | 227,488 | 225,043    | 227,226 | 224,991    | 227,713 | 225,541    | 228,564 | 226,522    |
|                                      | Chamber Pressure, psia                     | 779.6   | 767.0      | 778.8   | 766.9      | 780.3   | 768.5      | 782.8   | 771.7      |
|                                      | Mixture Ratio                              | 5.657   | 5.658      | 5.659   | 5.661      | 5.618   | 5.639      | 5.613   | 5.626      |
|                                      | Fuel Weight Flow, lb <sub>m</sub> /sec     | 81.37   | 80.08      | 81.49   | 80.26      | 81.99   | 80.58      | 82.20   | 80.94      |
|                                      | Oxidizer Weight Flow, lb <sub>m</sub> /sec | 460.3   | 453.1      | 461.1   | 454.4      | 460.6   | 454.4      | 461.4   | 455.4      |
|                                      | Total Weight Flow, lb <sub>m</sub> /sec    | 541.7   | 533.2      | 542.6   | 534.6      | 542.6   | 535.0      | 543.6   | 536.3      |
| Thrust<br>Chamber<br>Performance     | Mixture Ratio                              | 5.868   | 5.873      | 5.872   | 5.877      | 5.826   | 5.851      | 5.821   | 5.837      |
|                                      | Total Weight Flow, lb <sub>m</sub> /sec    | 534.7   | 526.3      | 535.6   | 527.7      | 535.6   | 528.1      | 536.6   | 529.4      |
|                                      | Characteristic Velocity, ft/sec            | 7991    | 7988       | 7968    | 7965       | 7984    | 7976       | 7996    | 7990       |
| Fuel<br>Turbopump<br>Performance     | Pump Efficiency, percent                   | 73.7    | 73.7       | 73.9    | 73.9       | 73.9    | 73.9       | 73.8    | 73.8       |
|                                      | Pump Speed, rpm                            | 26,349  | 26,162     | 26,377  | 26,185     | 26,453  | 26,166     | 26,362  | 26,192     |
|                                      | Turbine Efficiency, percent                | 58.5    | 58.4       | 58.4    | 58.3       | 59.1    | 58.8       | 58.9    | 58.8       |
|                                      | Turbine Pressure Ratio                     | 7.32    | 7.32       | 7.36    | 7.36       | 7.32    | 7.32       | 7.33    | 7.33       |
|                                      | Turbine Inlet Temperature, °F              | 1265    | 1247       | 1254    | 1236       | 1266    | 1245       | 1265    | 1250       |
| Oxidizer<br>Turbopump<br>Performance | Turbine Weight Flow, lb <sub>m</sub> /sec  | 6.97    | 6.90       | 6.99    | 6.93       | 6.96    | 6.90       | 6.99    | 6.93       |
|                                      | Pump Efficiency, percent                   | 80.3    | 80.3       | 80.3    | 80.3       | 80.3    | 80.3       | 80.3    | 80.3       |
|                                      | Pump Speed, rpm                            | 8667    | 8595       | 8663    | 8589       | 8667    | 8598       | 8679    | 8612       |
|                                      | Turbine Efficiency, percent                | 49.0    | 48.8       | 49.0    | 48.8       | 49.4    | 49.2       | 49.4    | 49.2       |
|                                      | Turbine Pressure Ratio                     | 2.58    | 2.58       | 2.58    | 2.58       | 2.59    | 2.59       | 2.57    | 2.57       |
| Gas<br>Generator<br>Performance      | Turbine Inlet Temperature, °F              | 843.5   | 830.3      | 833.7   | 820.5      | 834.6   | 820.4      | 841.3   | 830.2      |
|                                      | Turbine Weight Flow, lb <sub>m</sub> /sec  | 6.09    | 6.03       | 6.12    | 6.06       | 6.08    | 6.03       | 6.11    | 6.06       |
|                                      | Mixture Ratio                              | 0.978   | 0.967      | 0.972   | 0.961      | 0.979   | 0.967      | 0.979   | 0.969      |
| Gas<br>Generator<br>Performance      | Chamber Pressure, psia                     | 681.1   | 672.0      | 682.4   | 673.9      | 680.5   | 672.6      | 683.3   | 675.5      |

- Note: 1. Site data are calculated from test data.  
2. Normalized data are corrected to standard pump inlet and engine ambient pressure conditions.  
3. Input data are test data averaged from 29 to 30 sec, except as noted.  
4. Site and normalized data were computed using the Rocketdyne PAST 640 modification zero computer program.

### **APPENDIX III INSTRUMENTATION**

The instrumentation for AEDC tests J4-1901-07 and J4-1901-08 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

**TABLE III-1**  
**INSTRUMENTATION LIST**

| <u>AEDC</u><br><u>Code</u> | <u>Parameter</u>                      | <u>Tap</u><br><u>No.</u> | <u>Range</u>        | <u>Micro-</u><br><u>sadic</u> | <u>Magnetic</u><br><u>Tape</u> | <u>Oscillo-</u><br><u>graph</u> | <u>Strip</u><br><u>Chart</u> | <u>X-Y</u><br><u>Plotter</u> |
|----------------------------|---------------------------------------|--------------------------|---------------------|-------------------------------|--------------------------------|---------------------------------|------------------------------|------------------------------|
|                            | <u>Current</u>                        |                          | <u>amp</u>          |                               |                                |                                 |                              |                              |
| 1CC                        | Control                               |                          | 0 to 30             | x                             |                                | x                               |                              |                              |
| 1IC                        | Ignition                              |                          | 0 to 30             | x                             |                                | x                               |                              |                              |
|                            | <u>Event</u>                          |                          |                     |                               |                                |                                 |                              |                              |
| EASIOV                     | Augmented Spark Igniter               |                          |                     |                               |                                |                                 |                              |                              |
|                            | Oxidizer Valve                        |                          | Open/Closed         | x                             |                                | x                               |                              |                              |
| EECL                       | Engine Cutoff Lockin                  |                          | On/Off              | x                             |                                | x                               |                              |                              |
| EECO                       | Engine Cutoff Signal                  |                          | On/Off              | x                             | x                              | x                               |                              |                              |
| EES                        | Engine Start Command                  |                          | On/Off              | x                             |                                | x                               |                              |                              |
| EFBVC                      | Fuel Bleed Valve Closed Limit         |                          | Open/Closed         | x                             |                                |                                 |                              |                              |
| EFPVC/O                    | Fuel Prevalve Closed/Open Limit       |                          | Closed/Open         | x                             |                                |                                 |                              |                              |
| EHCS                       | Helium Control Solenoid               |                          | On/Off              | x                             |                                | x                               |                              |                              |
| EID                        | Ignition Detected                     |                          | On/Off              | x                             |                                | x                               |                              |                              |
| EIPCS                      | Ignition Phase Control Solenoid       |                          | On/Off              | x                             |                                | x                               |                              |                              |
| EMCS                       | Main-Stage Control Solenoid           |                          | On/Off              | x                             |                                | x                               |                              |                              |
| EMP-1                      | Main-Stage Pressure No. 1             |                          | On/Off              | x                             |                                | x                               |                              |                              |
| EMP-2                      | Main Stage Pressure No. 2             |                          | On/Off              | x                             |                                | x                               |                              |                              |
| EOBVC                      | Oxidizer Bleed Valve Closed Limit     |                          | Open/Closed         | x                             |                                |                                 |                              |                              |
| EOPVC                      | Oxidizer Prevalve Closed Limit        |                          | Closed              | x                             |                                | x                               |                              |                              |
| EOPVO                      | Oxidizer Prevalve Open Limit          |                          | Open                | x                             |                                | x                               |                              |                              |
| ESTDCS                     | Start Tank Discharge Control Solenoid |                          | On/Off              | x                             | x                              | x                               |                              |                              |
| RASIS-1                    | Augmented Spark Igniter Spark No. 1   |                          | On/Off              |                               |                                | x                               |                              |                              |
| RASIS-2                    | Augmented Spark Igniter Spark No. 2   |                          | On/Off              |                               |                                | x                               |                              |                              |
| RGGS-1                     | Gas Generator Spark No. 1             |                          | On/Off              |                               |                                | x                               |                              |                              |
| RGGS-2                     | Gas Generator Spark No. 2             |                          | On/Off              |                               |                                | x                               |                              |                              |
|                            | <u>Flows</u>                          |                          | <u>gpm</u>          |                               |                                |                                 |                              |                              |
| QF-1A                      | Fuel                                  | PFF                      | 0 to 9000           | x                             |                                | x                               |                              |                              |
| QF-2                       | Fuel                                  | PFFA                     | 0 to 9000           | x                             | x                              | x                               |                              |                              |
| QF-1SAM                    | Fuel Flow Stall Approach Monitor      |                          | 0 to 9000           | x                             |                                | x                               |                              |                              |
| QFRP                       | Fuel Recirculation                    |                          | 0 to 160            | x                             |                                |                                 |                              |                              |
| QO-1A                      | Oxidizer                              | POF                      | 0 to 3000           | x                             |                                | x                               |                              |                              |
| QO-2                       | Oxidizer                              | POFA                     | 0 to 3000           | x                             | x                              | x                               |                              |                              |
| QORP                       | Oxidizer Recirculation                |                          | 0 to 50             | x                             |                                |                                 |                              |                              |
|                            | <u>Position</u>                       |                          | <u>Percent Open</u> |                               |                                |                                 |                              |                              |
| LFVT                       | Main Fuel Valve                       |                          | 0 to 100            | x                             |                                | x                               |                              |                              |
| LGGVT                      | Gas Generator Valve                   |                          | 0 to 100            | x                             |                                | x                               |                              |                              |
| LOTBVT                     | Oxidizer Turbine Bypass Valve         |                          | 0 to 100            | x                             |                                | x                               |                              |                              |
| LOVT                       | Main Oxidizer Valve                   |                          | 0 to 100            | x                             |                                | x                               |                              |                              |
| LPUTOP                     | Propellant Utilization Valve          |                          | 0 to 100            | x                             |                                | x                               | x                            |                              |
| LSTDVT                     | Start Tank Discharge Valve            |                          | 0 to 100            | x                             |                                | x                               |                              |                              |
|                            | <u>Pressure</u>                       |                          | <u>psia</u>         |                               |                                |                                 |                              |                              |
| PA1                        | Test Cell                             |                          | 0 to 0.5            | x                             |                                | x                               |                              |                              |
| PA2                        | Test Cell                             |                          | 0 to 1.0            | x                             | x                              |                                 |                              |                              |
| PA3                        | Test Cell                             |                          | 0 to 5.0            | x                             |                                |                                 | x                            |                              |
| PC-1P                      | Thrust Chamber                        | CG1                      | 0 to 1000           | x                             |                                |                                 |                              |                              |
| PC-3                       | Thrust Chamber                        | CG1A                     | 0 to 1000           | x                             | x                              | x                               |                              |                              |
| PCBO-1                     | Constant Bleed Orifice                |                          | 0 to 50             | x                             |                                |                                 |                              |                              |
| PCDP                       | Crossover Duct Purge                  |                          | 0 to 100            | x                             |                                |                                 |                              |                              |
| PCGG-1P                    | Gas Generator Chamber                 |                          | 0 to 1000           | x                             | x                              | x                               |                              |                              |
| PCGG-2                     | Gas Generator Chamber                 | GG1A                     | 0 to 1000           | x                             |                                |                                 |                              |                              |
| PFBL                       | Fuel Bleed Line                       |                          | 0 to 100            | x                             |                                | x                               |                              |                              |
| PFJ-1A                     | Main Fuel Injection                   | CF2                      | 0 to 1000           | x                             |                                | x                               |                              |                              |
| PFJGG-1A                   | Gas Generator Fuel Injection          | GF4                      | 0 to 1000           | x                             |                                |                                 |                              |                              |
| PFJGG-2                    | Gas Generator Fuel Injection          | GF4                      | 0 to 1000           | x                             |                                | x                               |                              |                              |
| PFPC-1A                    | Fuel Pump Balance Piston Cavity       | PF5                      | 0 to 1000           | x                             |                                |                                 |                              |                              |
| PFPD-1P                    | Fuel Pump Discharge                   | PF3                      | 0 to 1500           | x                             |                                |                                 |                              |                              |
| PFPD-2                     | Fuel Pump Discharge                   | PF2                      | 0 to 1500           | x                             | x                              | x                               |                              |                              |
| PFP1-1                     | Fuel Pump Inlet                       |                          | 0 to 100            | x                             |                                | x                               |                              | x                            |
| PFP1-2                     | Fuel Pump Inlet                       |                          | 0 to 100            | x                             |                                | x                               |                              | x                            |

TABLE III-1 (Continued)

| AEDC<br>Code        | Parameter                          | Tap<br>No. | Range        | Micro-<br>sadic | Magnetic<br>Tape | Oscillo-<br>graph | Strip<br>Chart | X-Y<br>Plotter |
|---------------------|------------------------------------|------------|--------------|-----------------|------------------|-------------------|----------------|----------------|
| <u>Pressure</u>     |                                    |            | <u>psia</u>  |                 |                  |                   |                |                |
| PFPI-3              | Fuel Pump Inlet                    |            | 0 to 200     |                 | x                |                   |                |                |
| PFPPSD-1            | Fuel Pump Primary Seal Drain       |            | 0 to 200     | x               |                  |                   |                |                |
| PFRPO               | Fuel Recirculation Pump Outlet     |            | 0 to 60      | x               |                  |                   |                |                |
| PFRPR               | Fuel Recirculation Pump Return     |            | 0 to 50      | x               |                  |                   |                |                |
| PFST-1P             | Fuel Start Tank                    | TF1        | 0 to 1500    | x               |                  | x                 |                |                |
| PFST-2              | Fuel Start Tank                    | TF1        | 0 to 1500    | x               |                  |                   |                | x              |
| PFUT                | Fuel Tank Ullage                   |            | 0 to 100     | x               |                  |                   |                |                |
| PFVI                | Fuel Tank Pressurization Line      |            |              |                 |                  |                   |                |                |
|                     | Nozzle Inlet                       |            | 0 to 1000    | x               |                  |                   |                |                |
| PFVL                | Fuel Tank Pressurization Line      |            |              |                 |                  |                   |                |                |
|                     | Nozzle Throat                      |            | 0 to 1000    | x               |                  |                   |                |                |
| PHECMO              | Pneumatic Control Module Outlet    |            | 0 to 750     | x               |                  |                   |                |                |
| PHEOP               | Oxidizer Recirculation Pump Purge  |            | 0 to 150     | x               |                  |                   |                |                |
| PHET-1P             | Helium Tank                        | NN1        | 0 to 3500    | x               |                  | x                 |                |                |
| PHET-2              | Helium Tank                        | NN1        | 0 to 3500    | x               |                  |                   |                | x              |
| PHRO-1A             | Helium Regulator Outlet            | NN2        | 0 to 750     | x               |                  |                   |                |                |
| POJ-1A              | Main Oxidizer Injection            | CO3        | 0 to 1000    | x               |                  | x                 |                |                |
| POJ-2               | Main Oxidizer Injection            | CO3A       | 0 to 1000    | x               |                  | x                 |                |                |
| POJ-3               | Main Oxidizer Injection            |            | 0 to 2000    |                 | x                |                   |                |                |
| POJGG-1A            | Gas Generator Oxidizer Injection   | GO5        | 0 to 1000    | x               |                  | x                 |                |                |
| POJGG-2             | Gas Generator Oxidizer Injection   | GO5        | 0 to 1000    | x               |                  |                   |                |                |
| POPBC-1A            | Oxidizer Pump Bearing Coolant      | PO7        | 0 to 500     | x               |                  |                   |                |                |
| POPD-1P             | Oxidizer Pump Discharge            | PO3        | 0 to 1500    | x               |                  |                   |                |                |
| POPD-2              | Oxidizer Pump Discharge            | PO2        | 0 to 1500    | x               | x                | x                 |                |                |
| POPI-1              | Oxidizer Pump Inlet                |            | 0 to 100     | x               |                  |                   |                | x              |
| POPI-2              | Oxidizer Pump Inlet                |            | 0 to 200     | x               |                  |                   |                | x              |
| POPI-3              | Oxidizer Pump Inlet                |            | 0 to 100     |                 |                  | x                 |                |                |
| POPSC-1A            | Oxidizer Pump Primary Seal         |            |              |                 |                  |                   |                |                |
|                     | Cavity                             | PO6        | 0 to 50      | x               |                  |                   |                |                |
| PORPO               | Oxidizer Recirculation Pump        |            |              |                 |                  |                   |                |                |
|                     | Outlet                             |            | 0 to 115     | x               |                  |                   |                |                |
| PORPR               | Oxidizer Recirculation Pump Return |            | 0 to 100     | x               |                  |                   |                |                |
| POT1-1A             | Oxidizer Turbine Inlet             | TG3        | 0 to 200     | x               |                  |                   |                |                |
| POTO-1A             | Oxidizer Turbine Outlet            | TG4        | 0 to 100     | x               |                  |                   |                |                |
| POUT                | Oxidizer Tank Ullage               |            | 0 to 100     | x               |                  |                   |                |                |
| POVCC               | Main Oxidizer Valve Closing        |            |              |                 |                  |                   |                |                |
|                     | Control                            |            | 0 to 500     | x               |                  |                   |                |                |
| POV1                | Oxidizer Tank Pressurization       |            |              |                 |                  |                   |                |                |
|                     | Line Nozzle Inlet                  |            | 0 to 1000    | x               |                  |                   |                |                |
| POVL                | Oxidizer Tank Pressurization Line  |            |              |                 |                  |                   |                |                |
|                     | Nozzle Throat                      |            | 0 to 1000    | x               |                  |                   |                |                |
| PPUVI-1A            | Propellant Utilization Valve Inlet | PO8        | 0 to 1500    | x               |                  |                   |                |                |
| PPUVO-1A            | Propellant Utilization Valve       |            |              |                 |                  |                   |                |                |
|                     | Outlet                             | PO9        | 0 to 500     | x               |                  |                   |                |                |
| PTCFJP              | Thrust Chamber Fuel Jacket         |            |              |                 |                  |                   |                |                |
|                     | Purge                              |            | 0 to 100     | x               |                  |                   |                |                |
| PTCP                | Thrust Chamber Purge               |            | 0 to 1000    | x               |                  |                   |                |                |
| PTPP                | Turbopump and Gas Generator        |            |              |                 |                  |                   |                |                |
|                     | Purge                              |            | 0 to 250     | x               |                  |                   |                |                |
| <u>Speeds</u>       |                                    |            | <u>rpm</u>   |                 |                  |                   |                |                |
| NFP-1P              | Fuel Pump                          | PFV        | 0 to 30,000  | x               | x                | x                 |                |                |
| NFRP                | Fuel Recirculation Pump            |            | 0 to 15,000  | x               |                  |                   |                |                |
| NOP-1P              | Oxidizer Pump                      | POV        | 0 to 12,000  | x               | x                | x                 |                |                |
| NORP                | Oxidizer Recirculation Pump        |            | 0 to 15,000  | x               |                  |                   |                |                |
| <u>Temperatures</u> |                                    |            | <u>°F</u>    |                 |                  |                   |                |                |
| TA1                 | Test Cell (North)                  |            | -50 to +800  | x               |                  |                   |                |                |
| TA2                 | Test Cell (East)                   |            | -50 to +800  | x               |                  |                   |                |                |
| TA3                 | Test Cell (South)                  |            | -50 to +800  | x               |                  |                   |                |                |
| TA4                 | Test Cell (West)                   |            | -50 to +800  | x               |                  |                   |                |                |
| TA1P-1A             | Auxiliary Instrument Package       |            | -300 to +200 | x               |                  |                   |                |                |
| TA1PAA              | Auxiliary Instrument Package       |            |              |                 |                  |                   |                |                |
|                     | Area Ambient                       |            | -200 to +500 | x               |                  |                   |                |                |
| TCDP                | Crossover Duct Purge               |            | -150 to +150 | x               |                  |                   |                |                |

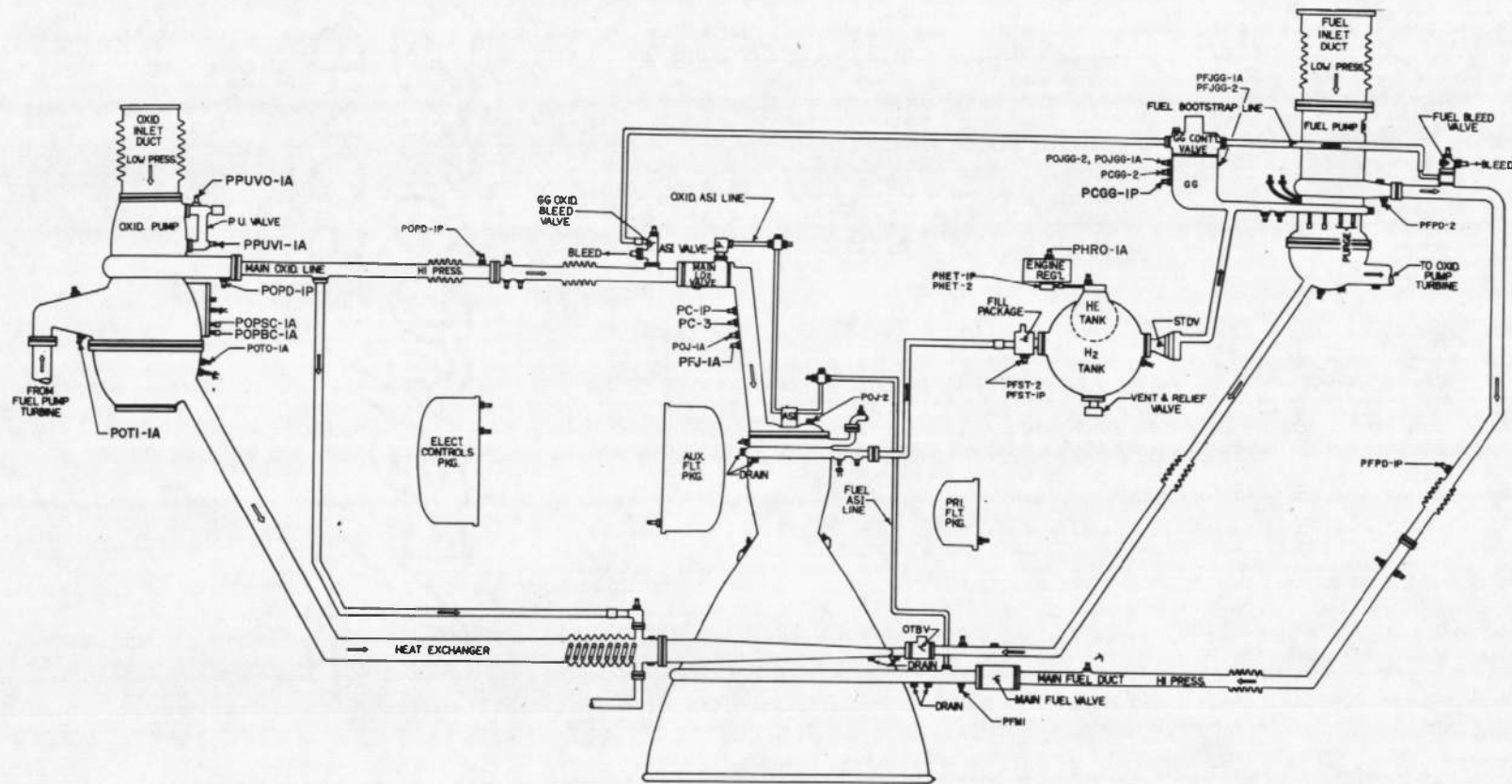
TABLE III-1 (Continued)

| AEDC<br>Code        | Parameter                           | Tap<br>No. | Range         | Micro-<br>sadic | Magnetic<br>Tape | Oscillo-<br>graph | Strip<br>Chart | X-Y<br>Plotter |
|---------------------|-------------------------------------|------------|---------------|-----------------|------------------|-------------------|----------------|----------------|
| <u>Temperatures</u> |                                     |            | <u>°F</u>     |                 |                  |                   |                |                |
| TECP-1P             | Electrical Controls Package         | NST1A      | -300 to +200  | x               |                  |                   | x              |                |
| TEHAA               | Engine Handler Attach               |            |               |                 |                  |                   |                |                |
|                     | Area Ambient                        |            | -200 to +500  | x               |                  |                   |                |                |
| TFASIL-2            | Augmented Spark Igniter Fuel        |            |               |                 |                  |                   |                |                |
|                     | Line Skin                           |            | -400 to +300  | x               |                  |                   |                |                |
| TFASIL-4            | Augmented Spark Igniter Fuel        |            |               |                 |                  |                   |                |                |
|                     | Line Skin                           |            | -425 to +500  | x               |                  |                   |                |                |
| TFBV-1A             | Fuel Bleed Valve                    | GFT1       | -425 to -375  | x               |                  |                   |                |                |
| TFD-1               | Fire Detection                      |            | 0 to 1000     | x               |                  |                   | x              |                |
| TFDAA               | Fuel High Pressure Duct             |            |               |                 |                  |                   |                |                |
|                     | Area Ambient                        |            | -200 to +500  | x               |                  |                   |                |                |
| TFJ-1P              | Main Fuel Injection                 | CFT2       | -425 to +250  | x               |                  | x                 |                |                |
| TFJ-2               | Main Fuel Injection                 |            | -450 to +250  | x               |                  |                   |                |                |
| TFPD-1P             | Fuel Pump Discharge                 | PFT1       | -425 to -400  | x               | x                | x                 |                |                |
| TFPD-2              | Fuel Pump Discharge                 | PFT1       | -425 to -400  | x               |                  |                   |                |                |
| TFPI-1              | Fuel Pump Inlet                     |            | -425 to -400  | x               |                  |                   |                | x              |
| TFPI-2              | Fuel Pump Inlet                     |            | -425 to -400  | x               |                  |                   |                | x              |
| TFRPO               | Fuel Recirculation Pump Outlet      |            | -425 to -350  | x               |                  |                   |                |                |
| TFRPR               | Fuel Recirculation Pump Return Line |            | -425 to -250  | x               |                  |                   |                |                |
| TFRT-1              | Fuel Tank                           |            | -425 to -410  | x               |                  |                   |                |                |
| TFRT-3              | Fuel Tank                           |            | -425 to -410  | x               |                  |                   |                |                |
| TFST-1P             | Fuel Start Tank                     | TFT1       | -350 to +100  | x               |                  |                   |                |                |
| TFST-2              | Fuel Start Tank                     | TFT1       | -350 to +100  | x               |                  |                   |                | x              |
| TFTD-2              | Fuel Turbine Discharge Duct         |            | -200 to +1000 | x               |                  |                   | x              |                |
| TFTD-3              | Fuel Turbine Discharge Duct         |            | -200 to +1000 | x               |                  |                   | x              |                |
| TFTD-4              | Fuel Turbine Discharge Duct         |            | -200 to +1000 | x               |                  |                   | x              |                |
| TFTD-8              | Fuel Turbine Discharge Duct         |            | -200 to +1400 | x               |                  |                   | x              |                |
| TFTO                | Fuel Turbine Outlet                 | TGT2       | 0 to 1800     | x               |                  |                   |                |                |
| TFTSD-1             | Fuel Turbine Seal Drain Line        |            | -300 to +100  | x               |                  |                   |                |                |
| TGGO-1A             |                                     |            |               |                 |                  |                   |                |                |
| and 2               | Gas Generator Outlet                | GGT1       | 0 to 2500     | x               |                  | x                 | x              |                |
| TGGVRS              | Gas Generator Valve                 |            |               |                 |                  |                   |                |                |
|                     | Retaining Screw                     |            | -100 to +100  | x               |                  |                   |                |                |
| THET-1P             | Helium Tank                         | NNT1       | -350 to +100  | x               |                  |                   |                | x              |
| TNODP               | Oxidizer Dome Purge                 |            | 0 to +300     | x               |                  |                   |                |                |
| TOASIL-1            | Augmented Spark Igniter             |            |               |                 |                  |                   |                |                |
|                     | Oxidizer Line Skin                  |            | -425 to +500  | x               |                  |                   |                |                |
| TOASIL-2            | Augmented Spark Igniter             |            |               |                 |                  |                   |                |                |
|                     | Oxidizer Line Skin                  |            | -400 to +300  | x               |                  |                   |                |                |
| TOBS-1              | Oxidizer Bootstrap Line             |            | -300 to +250  | x               |                  |                   |                |                |
| TOBS-2              | Oxidizer Bootstrap Line             |            | -300 to +250  | x               |                  |                   |                |                |
| TOBS-2B             | Oxidizer Bootstrap Line             |            | -300 to +250  | x               |                  |                   |                |                |
| TOBV-1A             | Oxidizer Bleed Valve                | GOT2       | -300 to -250  | x               |                  |                   |                |                |
| TODAA               | Oxidizer Dome Area Ambient          |            | -200 to +500  | x               |                  |                   |                |                |
| TODS-1              | Oxidizer Dome Skin                  |            | -300 to +100  | x               |                  |                   | x              |                |
| TODS-2              | Oxidizer Dome Skin                  |            | -300 to +100  | x               |                  |                   | x              |                |
| TOPB-1A             | Oxidizer Pump Bearing Coolant       | POT4       | -300 to -250  | x               |                  |                   |                |                |
| TOPD-1P             | Oxidizer Pump Discharge             | POT3       | -300 to -250  | x               | x                | x                 | x              |                |
| TOPD-2              | Oxidizer Pump Discharge             | POT3       | -300 to -250  | x               |                  |                   |                |                |
| TOPI-1              | Oxidizer Pump Inlet                 |            | -310 to -270  | x               |                  |                   |                | x              |
| TOPI-2              | Oxidizer Pump Inlet                 |            | -310 to -270  | x               |                  |                   |                | x              |
| TORPO               | Oxidizer Recirculation Pump Outlet  |            | -300 to -250  | x               |                  |                   |                |                |
| TORPR               | Oxidizer Recirculation Pump Return  |            | -300 to -140  | x               |                  |                   |                |                |
| TORT-1              | Oxidizer Tank                       |            | -300 to -287  | x               |                  |                   |                |                |
| TORT-1B             | Oxidizer Tank                       |            | -300 to -287  | x               |                  |                   |                |                |
| TORT-3              | Oxidizer Tank                       |            | -300 to -287  | x               |                  |                   |                |                |
| TOTI-1P             | Oxidizer Turbine Inlet              | TGT3       | -300 to 1200  | x               |                  |                   | x              |                |
| TOTO-1P             | Oxidizer Turbine Outlet             | TGT4       | 0 to 1000     | x               |                  |                   |                |                |
| TOVL                | Oxidizer Tank Pressurization        |            |               |                 |                  |                   |                |                |
|                     | Line Nozzle Throat                  |            | -300 to +100  | x               |                  |                   |                |                |
| TP1P-1P             | Primary Instrument Package          |            | -300 to +200  | x               |                  |                   |                |                |
| TP1PAA              | Primary Instrument Package          |            |               |                 |                  |                   |                |                |
|                     | Area Ambient                        |            | -200 to +500  | x               |                  |                   |                |                |

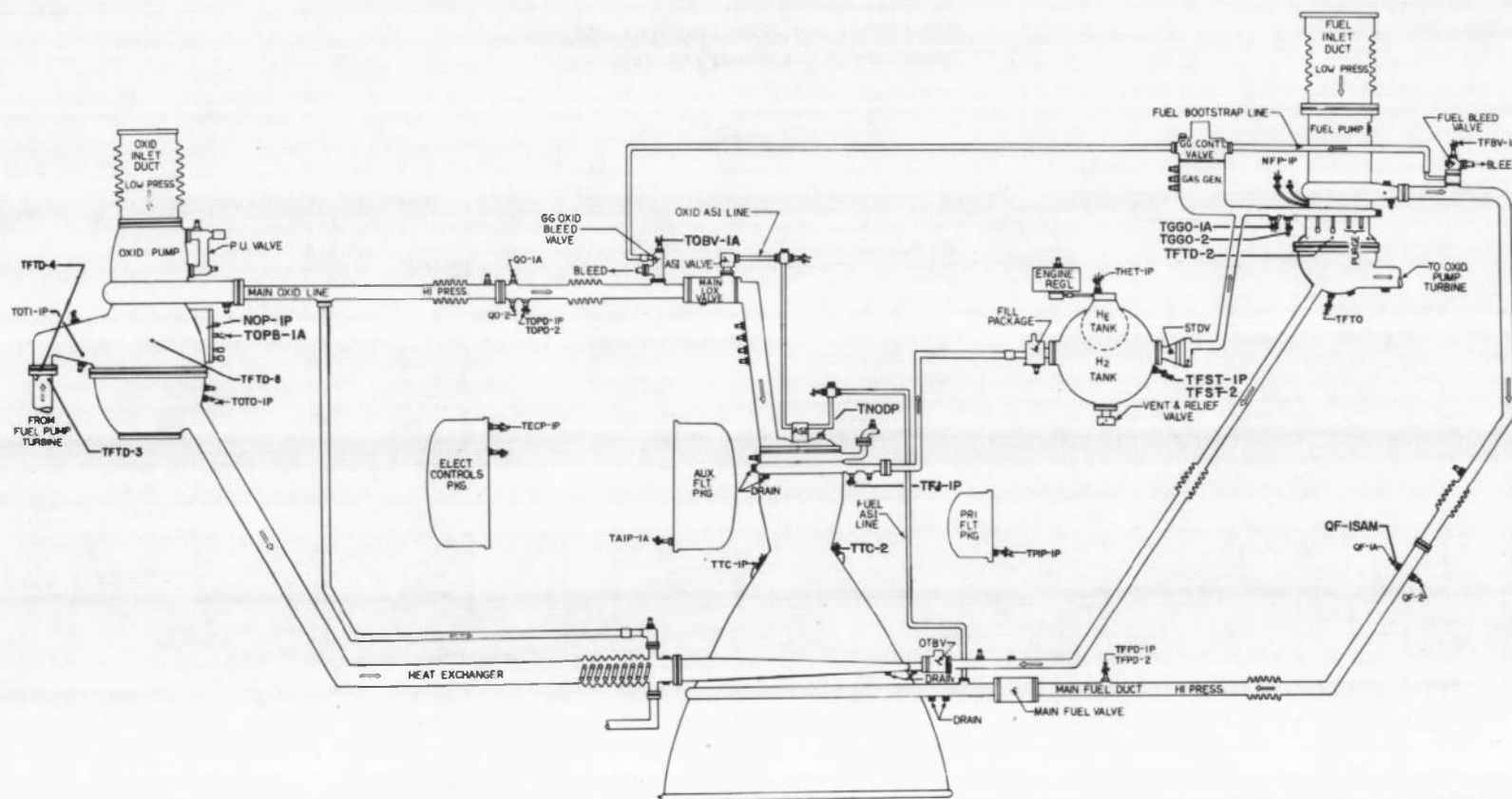
TABLE III-1 (Concluded)

| <u>AEDC<br/>Code</u> | <u>Parameter</u>   | <u>Tap<br/>No.</u> | <u>Range</u> | <u>Micro-<br/>sadc</u> | <u>Magnetic<br/>Tape</u> | <u>Oscillo-<br/>graph</u> | <u>Strip<br/>Chart</u> | <u>X-Y<br/>Plotter</u> |
|----------------------|--|--------------------|--------------|------------------------|--------------------------|---------------------------|------------------------|------------------------|
| <u>Temperatures</u>  |  |                    | <u>°F</u>    |                        |                          |                           |                        |                        |
| TSC2-1               | Thrust Chamber Skin                                      |                    | -300 to +500 | x                      |                          |                           |                        |                        |
| TSC2-12              | Thrust Chamber Skin                                      |                    | -300 to +500 | x                      |                          |                           |                        |                        |
| TSC2-13              | Thrust Chamber Skin                                      |                    | -300 to +500 | x                      |                          |                           | x                      |                        |
| TSC2-17              | Thrust Chamber Skin                                      |                    | -300 to +500 | x                      |                          |                           |                        |                        |
| TSC2-20              | Thrust Chamber Skin                                      |                    | -300 to +500 | x                      |                          |                           |                        |                        |
| TSC2-24              | Thrust Chamber Skin                                      |                    | -300 to +500 | x                      |                          |                           |                        |                        |
| TSOVC-1              | Oxidizer Valve Actuator Cap                              | NST1               | -325 to +150 | x                      |                          |                           | x                      |                        |
| TSTDVAA              | Start Tank Discharge Valve<br>Area Ambient               |                    | -200 to +500 | x                      |                          |                           |                        |                        |
| TSTDVDL              | Start Tank Discharge Valve<br>Drain Line Port            |                    | -100 to +200 | x                      |                          |                           |                        |                        |
| TSTDVOC              | Start Tank Discharge Valve Opening<br>Control Port       |                    | -300 to +200 | x                      |                          |                           |                        |                        |
| TTC-1P               | Thrust Chamber Jacket (Control)                          | CS1                | -425 to +500 | x                      |                          |                           | x                      |                        |
| TTC-2                | Thrust Chamber Jacket                                    | CS1A               | -425 to +100 | x                      |                          |                           |                        |                        |
| TTCP                 | Thrust Chamber Purge                                     |                    | -346 to +504 | x                      |                          |                           |                        |                        |
| TTPP                 | Turbopump Purge  |                    | -150 to +150 | x                      |                          |                           | x                      |                        |
| <u>Vibrations</u>    |  |                    | <u>g's</u>   |                        |                          |                           |                        |                        |
| USAIF-1              | Augmented Spark Igniter Fuel<br>Orifice Block Tangential |                    | ±150         |                        | x                        |                           |                        |                        |
| UASIV-1              | Augmented Spark Igniter Oxidizer<br>Valve Axial          |                    | ±150         |                        | x                        |                           |                        |                        |
| UASIV-3              | Augmented Spark Igniter Oxidizer<br>Valve Tangential     |                    | ±150         |                        | x                        |                           |                        |                        |
| UFPR                 | Fuel Pump Radial 90 deg                                  |                    | ±300         |                        | x                        | x                         |                        |                        |
| UMFV-1               | Main Fuel Valve Radial                                   |                    | ±150         |                        | x                        |                           |                        |                        |
| UMFV-3               | Main Fuel Valve Tangential                               |                    | ±150         |                        | x                        |                           |                        |                        |
| UOPR                 | Oxidizer Pump Radial 90 deg                              |                    | ±200         |                        | x                        |                           |                        |                        |
| UOTBV-1              | Oxidizer Turbine Bypass Valve Axial                      |                    | ±150         |                        | x                        |                           |                        |                        |
| UTCD-1               | Thrust Chamber Dome                                      |                    | ±500         |                        | x                        | x                         |                        |                        |
| UTCD-2               | Thrust Chamber Dome                                      |                    | ±500         |                        | x                        | x                         |                        |                        |
| UTCD-3               | Thrust Chamber Dome                                      |                    | ±500         |                        | x                        |                           |                        |                        |
| UTCD-4               | Thrust Chamber Dome                                      |                    | ±1000        |                        |                          | x                         |                        |                        |
| U1VSC                | No. 1 Vibration Safety Counts                            |                    | On/Off       |                        |                          | x                         |                        |                        |
| U2VSC                | No. 2 Vibration Safety Counts                            |                    | On/Off       |                        |                          | x                         |                        |                        |
| U3VSC                | No. 3 Vibration Safety Counts                            |                    | On/Off       |                        |                          | x                         |                        |                        |
| <u>Voltage</u>       |  |                    | <u>volts</u> |                        |                          |                           |                        |                        |
| VCB                  | Control Bus  |                    | 0 to 36      | x                      |                          | x                         |                        |                        |
| VIB                  | Ignition Bus   |                    | 0 to 36      | x                      |                          | x                         |                        |                        |
| VIDA                 | Ignition Detect Amplifier                                |                    | 9 to 16      | x                      |                          | x                         |                        |                        |
| VPUTEP               | Propellant Utilization Valve Excitation                  |                    | 0 to 6       | x                      |                          |                           |                        |                        |

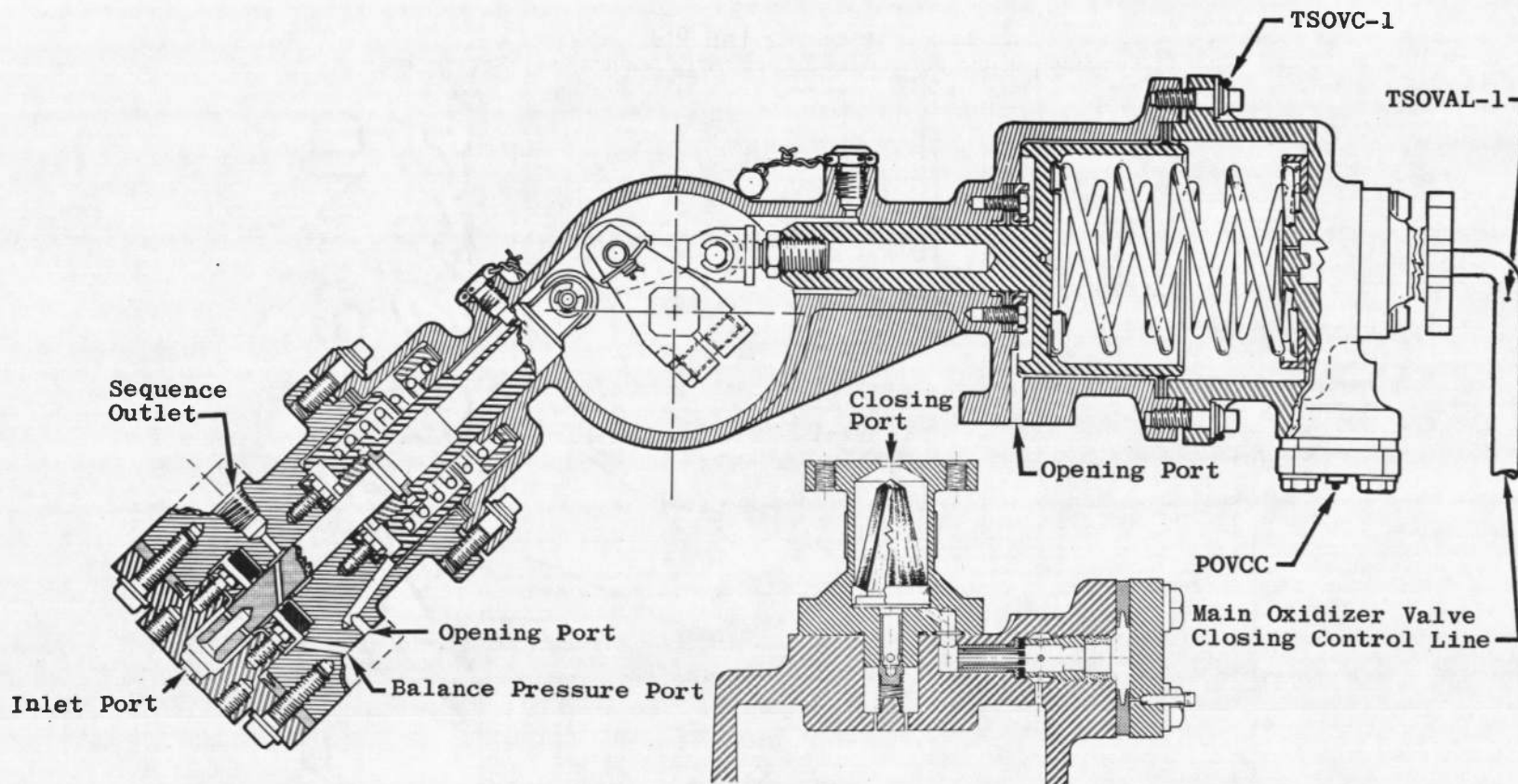




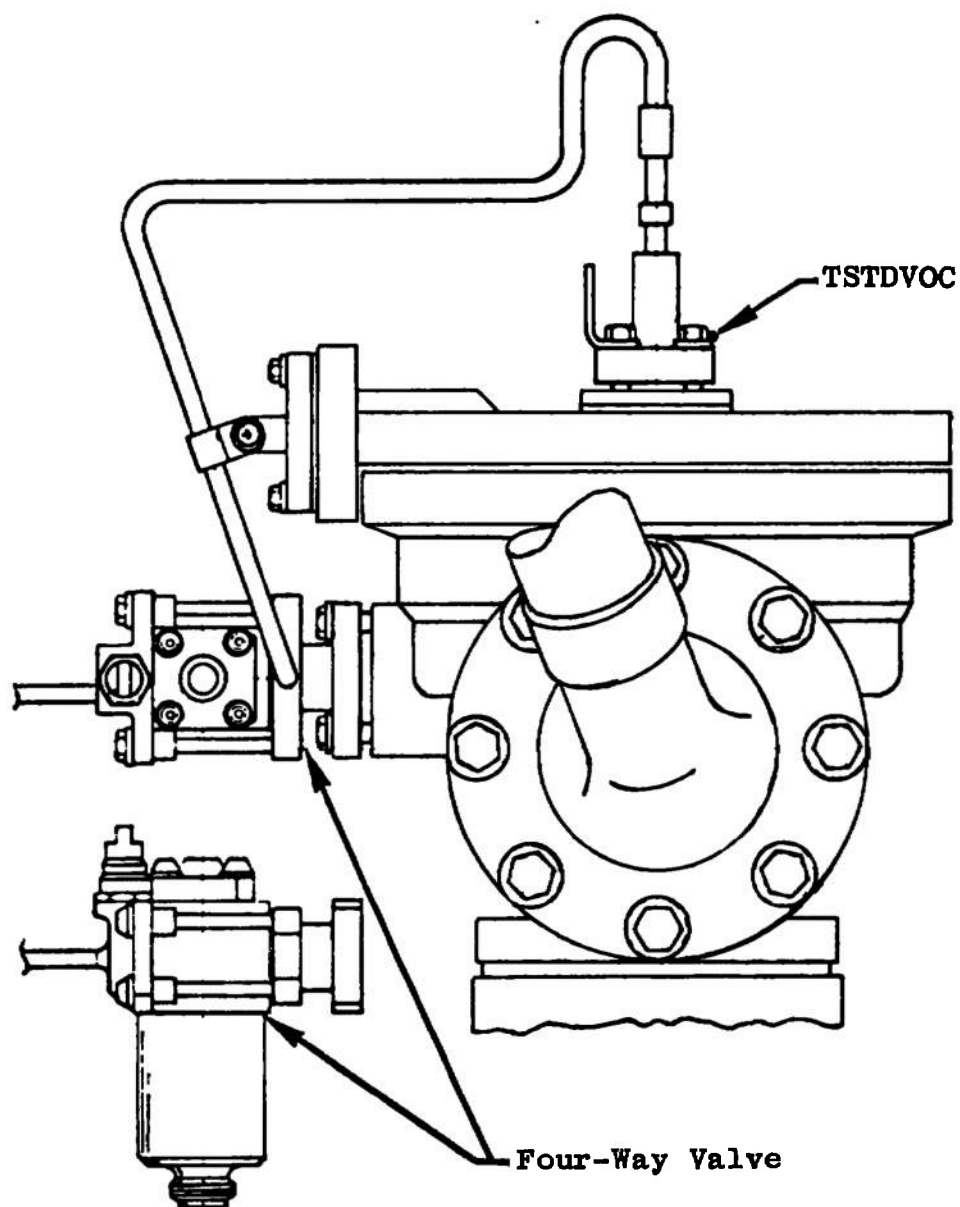
a. Engine Pressure Tap Locations  
Fig. III-1 Instrumentation Locations



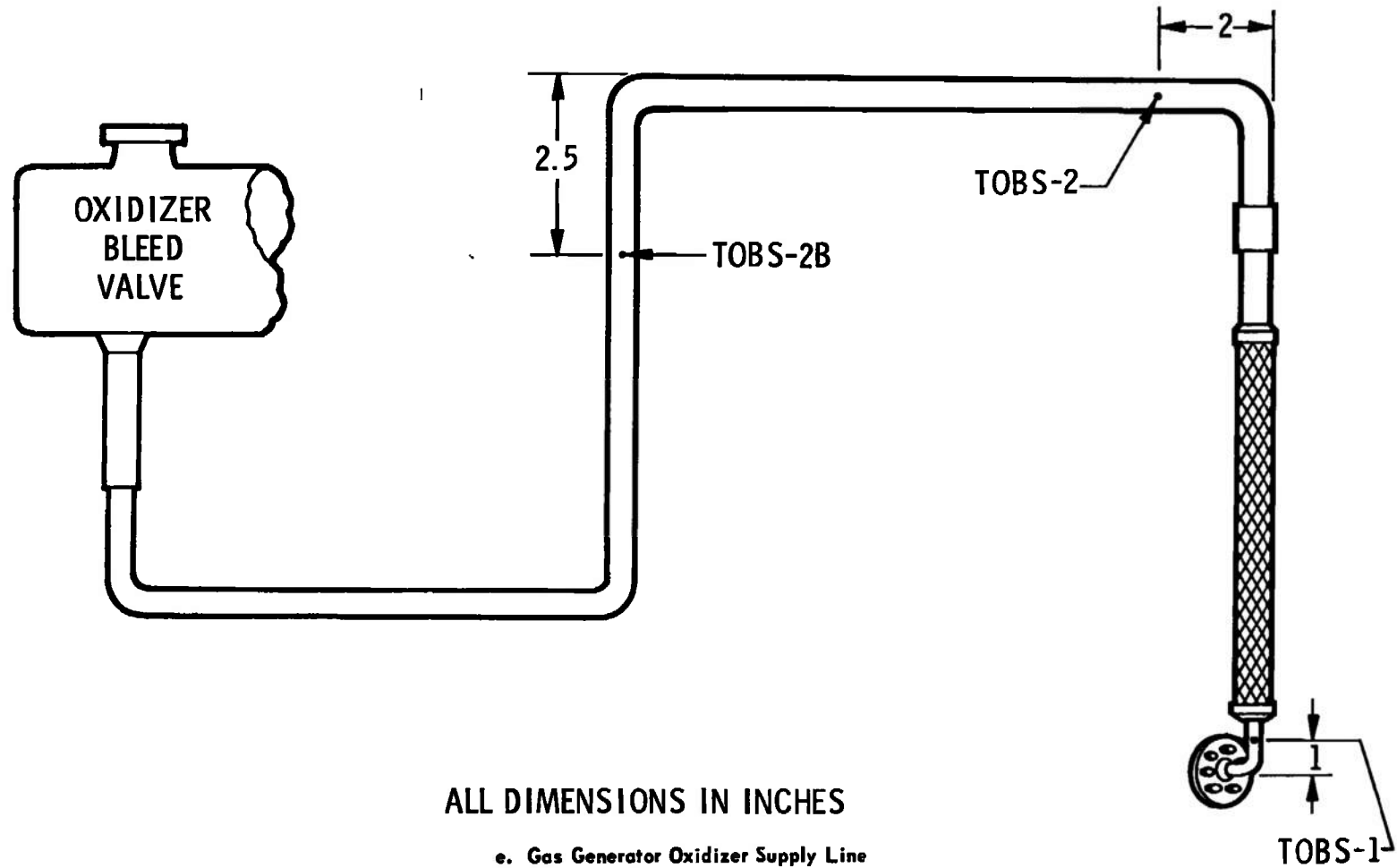
b. Engine Temperature, Flow, and Speed Instrumentation Locations  
Fig. III-1 Continued



c. Main Oxidizer Valve  
Fig. III-1 Continued



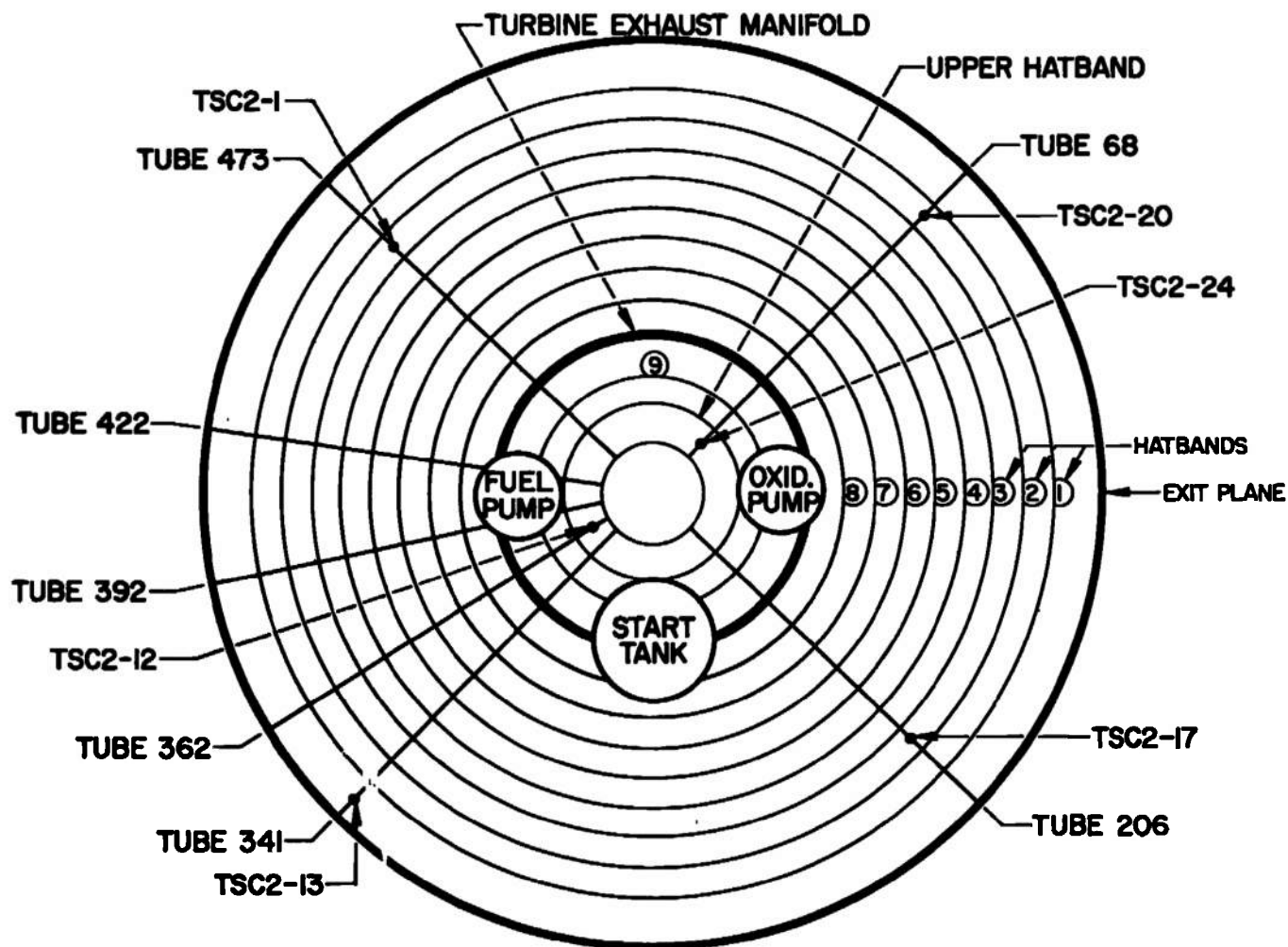
d. Start Tank Discharge Valve  
Fig. III-1 Continued



ALL DIMENSIONS IN INCHES

e. Gas Generator Oxidizer Supply Line

Fig. III-1 Continued



VIEW LOOKING AFT

f. Thrust Chamber  
Fig. III-1 Concluded

**APPENDIX IV**  
**METHOD OF CALCULATION (PERFORMANCE PROGRAM)**

**TABLE IV-1**  
**PERFORMANCE PROGRAM DATA INPUTS**

| Item No. | Parameter   |
|----------|---|
| 1        | Thrust Chamber (Injector Face) Pressure, psia                 |
| 2        | Thrust Chamber Fuel and Oxidizer Injection Pressures, psia    |
| 3        | Thrust Chamber Fuel Injection Temperature, °F                 |
| 4        | Fuel and Oxidizer Flowmeter Speeds, Hz                        |
| 5        | Fuel and Oxidizer Engine Inlet Pressures, psia                |
| 6        | Fuel and Oxidizer Pump Discharge Pressures, psia              |
| 7        | Fuel and Oxidizer Engine Inlet Temperatures, °F               |
| 8        | Fuel and Oxidizer (Main Valves) Temperatures, °F              |
| 9        | Propellant Utilization Valve Center Tap Voltage, volts        |
| 10       | Propellant Utilization Valve Position, volts                  |
| 11       | Fuel and Oxidizer Pump Speeds, rpm                            |
| 12       | Gas Generator Chamber Pressure, psia                          |
| 13       | Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F |
| 14       | Fuel* and Oxidizer Turbine Inlet Pressure, psia               |
| 15       | Oxidizer Turbine Discharge Pressure, psia                     |
| 16       | Fuel and Oxidizer Turbine Inlet Temperature, °F               |
| 17       | Oxidizer Turbine Discharge Temperature, °F                    |

\*At AEDC, fuel turbine inlet pressure is calculated from gas generator chamber pressure.

## NOMENCLATURE

|     |   |
|-----|---|
| A   | Area, in. <sup>2</sup>  |
| B   | Horsepower  |
| C   | Coefficient   |
| C*  | Characteristic velocity, ft/sec                                 |
| D   | Diameter, in.   |
| F   | Thrust, lbf   |
| H   | Head, ft  |
| h   | Enthalpy, Btu/lb <sub>m</sub>                                   |
| I   | Impulse   |
| M   | Molecular weight  |
| N   | Speed, rpm  |
| P   | Pressure, psia  |
| Q   | Flow rate, gpm  |
| R   | Resistance, sec <sup>2</sup> /ft <sup>3</sup> -in. <sup>2</sup> |
| r   | Mixture ratio, O/F  |
| T   | Temperature, °F   |
| TC* | Theoretical characteristic velocity, ft/sec                     |
| W   | Weight flow, lb/sec   |
| Z   | Differential pressure, psi                                      |
| β   | Ratio   |
| γ   | Ratio of specific heats   |
| η   | Efficiencies  |
| θ   | Degrees   |
| ρ   | Density, lb/ft <sup>3</sup>                                     |

## SUBSCRIPTS

|    |                                |
|----|--------------------------------|
| A  | Ambient                        |
| AA | Ambient at thrust chamber exit |
| B  | Bypass nozzle                  |



|     |                               |
|-----|-------------------------------|
| BIR | Bypass nozzle inlet (Rankine) |
| BNI | Bypass nozzle inlet (total)   |
| C   | Thrust chamber                |
| CF  | Thrust chamber, fuel          |
| CO  | Thrust chamber, oxidizer      |
| CV  | Thrust chamber, vacuum        |
| E   | Engine                        |
| EF  | Engine fuel                   |
| EM  | Engine measured               |
| EO  | Engine oxidizer               |
| EV  | Engine, vacuum                |
| e   | Exit                          |
| em  | Exit measured                 |
| F   | Thrust                        |
| FM  | Fuel measured                 |
| FV  | Thrust, vacuum                |
| f   | Fuel                          |
| G   | Gas generator                 |
| GF  | Gas generator fuel            |
| GO  | Gas generator oxidizer        |
| H1  | Hot gas duct No. 1            |
| H1R | Hot gas duct No. 1 (Rankine)  |
| H2R | Hot gas duct No. 2 (Rankine)  |
| IF  | Inlet fuel                    |
| IO  | Inlet oxidizer                |
| ITF | Isentropic turbine fuel       |
| ITO | Isentropic turbine oxidizer   |
| N   | Nozzle                        |
| NB  | Bypass nozzle (throat)        |

|      |                                       |
|------|---------------------------------------|
| NV   | Nozzle, vacuum                        |
| O    | Oxidizer                              |
| OC   | Oxidizer pump calculated              |
| OF   | Outlet fuel pump                      |
| OFIS | Outlet fuel pump isentropic           |
| OM   | Oxidizer measured                     |
| OO   | Oxidizer outlet                       |
| PF   | Pump fuel                             |
| PO   | Pump oxidizer                         |
| PUVO | Propellant utilization valve oxidizer |
| RNC  | Ratio bypass nozzle, critical         |
| SC   | Specific, thrust chamber              |
| SCV  | Specific thrust chamber, vacuum       |
| SE   | Specific, engine                      |
| SEV  | Specific, engine vacuum               |
| T    | Total                                 |
| TEF  | Turbine exit fuel                     |
| TEFS | Turbine exit fuel (static)            |
| TF   | Fuel turbine                          |
| TIF  | Turbine inlet fuel (total)            |
| TIFM | Turbine inlet, fuel, measured         |
| TIFS | Turbine inlet fuel isentropic         |
| TIO  | Turbine inlet oxidizer                |
| TO   | Turbine oxidizer                      |
| t    | Throat                                |
| V    | Vacuum                                |
| v    | Valve                                 |
| XF   | Fuel tank repressurant                |
| XO   | Oxidizer tank repressurant            |

## PERFORMANCE PROGRAM EQUATIONS

## THRUST

Thrust Chamber, Vacuum

$$F_{CV} = C (P_C)^2 + B (P_C) + A$$

Empirical Determination from Curve Fit of Thrust  
versus  $P_C$

Thrust Chamber

$$F_C = F_{CV} - P_{AA} A_e$$

$$A_e = A_{em} + 12.8$$

$$P_{AA} = \text{Measured Cell Pressure}$$

Engine, Vacuum

$$F_{EV} = F_{CV}$$

Engine

$$F_E = F_C$$

## MIXTURE RATIO

Engine

$$r_E = \frac{W_{EO}}{W_{EF}}$$

$$W_{EO} = W_{OM} - W_{XO}$$

$$W_{EF} = W_{FM} - W_{XF}$$

Thrust Chamber

$$r_C = \frac{W_{CO}}{W_{CF}}$$

$$W_{CO} = W_{OM} - W_{XO} - W_{GO}$$

$$W_{CF} = W_{FM} - W_{XF} - W_{GF}$$

$$W_{XO} = \text{Standard } 0.9 \text{ lb/sec}$$

$$W_{XF} = \text{Standard } 2.1 \text{ lb/sec}$$

$$W_{GO} = W_T - W_{GF}$$

$$W_{GF} = \frac{W_T}{1 + r_G}$$

$$W_T = \frac{P_{TIF} A_{TIF} K_7}{TC * TIF}$$

$$K_7 = 32.174$$

Normalized engine and thrust chamber vacuum data calculated as measured, except all flows are normalized using standard inlet pressures, temperatures, and densities listed below:

$$P_{I0} \text{ STD} = 39 \text{ psia}$$

$$P_{IF} \text{ STD} = 30 \text{ psia}$$

$$\rho_{I0} \text{ STD} = 70.79 \text{ lb/ft}^3$$

$$\rho_{IF} \text{ STD} = 4.40 \text{ lb/ft}^3$$

$$T_{I0} \text{ STD} = -295.2^\circ\text{F}$$

$$T_{IF} \text{ STD} = 422.5^\circ\text{F}$$

### SPECIFIC IMPULSE

Engine

$$I_{SE} = \frac{F_E}{W_E}$$

$$W_E = W_{EO} + W_{EF}$$

Engine, Vacuum

$$I_{SEV} = \frac{F_{EV}}{W_{EV}}$$

$$W_{EV} = W_E \text{ Normalized using standard inlet pressures, temperatures, and densities}$$

Chamber

$$I_{SC} = \frac{F_C}{W_C}$$

$$W_C = W_{CO} + W_{CF}$$

Chamber, Vacuum

$$I_{SCV} = \frac{F_{CV}}{W_{CV}}$$

$$W_{CV} = W_C \text{ Normalized using standard inlet pressures, temperatures, and densities}$$

### CHARACTERISTIC VELOCITY

Thrust Chamber

$$C^* = \frac{K_7 P_C A_t}{W_C}$$

$$K_7 = 32.174$$

Thrust Chamber, Vacuum

$$C^*_V = \frac{K_7 P_{CV} A_t}{W_{CV}}$$

$$K_7 = 32.174$$

Nozzle

$$C_N^* = \frac{C^*}{K_6}$$

$$K_6 = 1.086$$

Nozzle, Vacuum

$$C_{NV}^* = \frac{C_V^*}{K_6}$$

$$K_6 = 1.086$$

## THRUST COEFFICIENT

Engine

$$C_F = \frac{F_C}{P_C A_t}$$

Engine, Vacuum

$$C_{FV} = \frac{F_{CV}}{P_C A_t}$$

## DEVELOPED PUMP HEAD

Oxidizer

$$H_O = K_4 \left( \frac{P_{OO}}{\rho_{OO}} - \frac{P_{IO}}{\rho_{IO}} \right)$$

$$K_4 = 144$$

$$\rho = \text{National Bureau of Standards Values } f(P, T)$$

Fuel

$$H_F = 778.16 \Delta h_{OFIS}$$

$$\Delta h_{OFIS} = h_{OFIS} - h_{IF}$$

$$h_{OFIS} = f(P, T)$$

$$h_{IF} = f(P, T)$$

Fuel and Oxidizer Vacuum

Conditions normalized using standard inlet pressures, temperatures, and densities.

## PUMP EFFICIENCIES

Fuel, Isentropic

$$\eta_F = \frac{h_{OFIS} - h_{IF}}{h_{OF} - h_{IF}}$$

$$h_{OF} = f(P_{OF}, T_{OF})$$

## Oxidizer, Isentropic

$$\eta_O = \eta_{OC} Y_O$$

$$\eta_{OC} = K_{40} \left( \frac{Q_{PO}}{N_O} \right)^2 + K_{50} \left( \frac{Q_{PO}}{N_O} \right) + K_{60}$$

$$Y_O = 1.000$$

$$K_{40} = -5.053 \quad K_{50} = 3.861 \quad K_{60} = 0.0733$$

## TURBINES

## Oxidizer, Efficiency

$$\eta_{TO} = \frac{B_{TO}}{B_{ITO}}$$

$$B_{TO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_5 = 0.001818$$

$$W_{PO} = W_{OM} + W_{PUVO}$$

$$W_{PUVO} = \sqrt{\frac{Z_{PUVO} \rho_{OO}}{R_v}}$$

$$Z_{PUVO} = A + B (P_{OO})$$

$$A = -1597$$

$$B = 2.3828$$

$$\text{if } P_{OO} \geq 1010$$

$$\text{set } P_{OO} = 1010$$

$$\ln R_v = A + B (\theta_{PUVO}) + C(\theta_{PUVO})^3 + D \left( \frac{\theta_{PUVO}}{7} \right) + E \theta_{PUVO} \left( \frac{\theta_{PUVO}}{7} \right) + F \left[ \left( \frac{\theta_{PUVO}}{7} \right)^2 \right]$$

$$A = 5.566 \times 10^{-1}$$

$$B = 1.500 \times 10^{-2}$$

$$C = 7.941 \times 10^{-6}$$

$$D = 1.234$$

$$E = -7.255 \times 10^{-2}$$

$$F = 5.069 \times 10^{-2}$$

## Fuel, Efficiency

$$\eta_{TF} = \frac{B_{TF}}{B_{ITF}}$$

$$B_{ITF} = K_{10} \Delta h_F W_T$$

$$\Delta h_F = h_{TIF} - h_{TEF}$$

$$B_{TF} = B_{PF} = K_5 \left( \frac{W_{PF} H_F}{\eta_F} \right)$$

$$W_{PF} = W_{FM}$$

$$K_{10} = 1.415$$

$$K_5 = 0.001818$$

#### Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO}$$

$$B_{PO} = K_5 \left( \frac{W_{PO} H_O}{\eta_O} \right)$$

$$K_5 = 0.001818$$

#### Fuel, Developed Horsepower

$$B_{TF} = B_{PF}$$

$$B_{PF} = K_5 \left( \frac{W_{PF} H_F}{\eta_F} \right)$$

$$W_{PF} = W_{FM}$$

#### Fuel, Weight Flow

$$W_{TF} = W_T$$

$$W_{TO} = W_T - W_B$$

$$W_B = \left[ \frac{2K_7 \gamma_{H_2}}{\gamma_{H_2} - 1} (P_{RNC}) \frac{2}{\gamma_{H_2}} \right]^{\frac{1}{2}} \left[ 1 - (P_{RNC}) \frac{\gamma_{H_2} - 1}{\gamma_{H_2}} \right]^{\frac{1}{2}} \frac{A_{NB} P_{BNI}}{(R_{H_2} T_{BIR})^{\frac{1}{2}}}$$

$$P_{RNC} = f(\beta_{NB}, \gamma_{H_2})$$

$$\beta_{NB} = D_{NB}/D_B$$

$$\gamma_{H_2}, M_{H_2} = f(T_{H_2R}, r_G)$$

$$A_{NB} = K_{13} (D_{NB})^2$$

$$K_{13} = 0.7854$$

$$T_{BIR} = T_{TIO} + 460$$

$$P_{BNI} = P_{TEFS}$$

$$P_{TEFS} = \text{Iteration of } P_{TEF}$$

$$P_{TEF} = P_{TEFS} \left[ 1 + K_8 \left( \frac{W_T}{P_{TEFS}} \right)^2 \frac{T_{H2R}}{D_{TEF}^4 M_{H2}} \left( \frac{\gamma_{H2}-1}{\gamma_{H2}} \right) \right]^{\frac{\gamma_{H2}}{\gamma_{H2}-1}}$$

$$K_8 = 38.8983$$

## GAS GENERATOR

### Mixture Ratio

$$r_G = D_1 (T_{H1})^3 + C_1 (T_{H1})^2 + B_1 (T_{H1}) + A_1$$

$$A_1 = 0.2575$$

$$B_1 = 5.586 \times 10^{-4}$$

$$C_1 = -5.332 \times 10^{-9}$$

$$D_1 = 1.1312 \times 10^{-11}$$

$$T_{H1} = T_{TIFM}$$

### Flows

$$TC^*_{TIF} = D_2 (T_{H1})^3 + C_2 (T_{H1})^2 + B_2 (T_{H1}) + A_2$$

$$A_2 = 4.4226 \times 10^3$$

$$B_2 = 3.2267$$

$$C_2 = -1.3790 \times 10^{-3}$$

$$D_2 = 2.6212 \times 10^{-7}$$

$$P_{TIF} = P_{TIFS} \left[ 1 + K_8 \left( \frac{W_T}{P_{TIFS}} \right)^2 \frac{T_{H1R}}{D_{TIF}^4 M_{H1}} \frac{\gamma_{H1}-1}{\gamma_{H1}} \right]^{\frac{\gamma_{H1}}{\gamma_{H1}-1}}$$

$$K_8 = 38.8983$$

Note:  $P_{TIF}$  is determined by iteration.

$$T_{H1R} = T_{TIFM} + 460$$

$$M_{H1}, \gamma_{H1}, C_p, r_{H1} = f(T_{H1R}, r_G)$$



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| 13. ABSTRACT<br>Ten firings of the Rocketdyne J-2 rocket engine (S/N J-2036-1) were conducted during two test periods (J4-1901-07 and J4-1901-08) on August 21 and 27, 1968, in Test Cell J-4 of the Large Rocket Facility. This testing was in support of the Saturn V vehicle. The firings were accomplished at pressure altitudes between 93,000 and 102,000 ft at engine start. The primary objective of these firings was to evaluate transient gas generator temperatures under simulated engine first burn and restart conditions. Transient gas generator temperatures, particularly on engine restarts, were significantly reduced by utilizing a gas generator oxidizer supply line assembly which incorporated a geometrically different bellows section. The supply line assembly utilized on this series of firings had a 1.7 percent greater pressure drop at a flow of 3.5 lb <sub>m</sub> /sec. The total accumulated firing duration for these tests was 163 sec.<br><br>This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama 35812 |  |   |                      |

## KEY WORDS

## performance evaluation

2 " " - - Performance